Glasgow
Naval and Marine Engineering Exhibition,
1880-81.



# Lectures on Naval Architecture and Engineering.

With Catalogue of the Exhibition.

London and Glasgow:
William Collins, Sons, & Co. (Limited).
1881.

Printed by
Robert Anderson, 22 Ann Street,
Glasgow.

# PREFATORY NOTE.

THE Lectures which form the greater part of this volume were delivered in connection with an Exhibition of Naval Architecture and Marine Engineering in Glasgow, during the winter season of 1880-81. The Exhibition was initiated by the Museum Committee of the Town Council of Glasgow; but the dimensions it attained, and the large measure of success which attended the undertaking, were principally due to the efforts of a Committee of Shipbuilders and Engineers of the Clyde and other districts, by whom the active duties of the Exhibition were directed. The nature and scope of the Exhibition itself, and the sources whence the objects shown were drawn, will best be learnt from the Catalogue, which forms an appendix to this volume.

No attempt was made by the Committee to render this course of Lectures in any sense consecutive and systematic. Each lecturer chose his own subject, without regard to or knowledge of the subject of the others; and, as the separate Lectures are thus complete in themselves and entirely independent of each other, they have been simply printed in the order in which they were delivered. It is right to say that the Lectures were delivered gratuitously; and the Committee are under deep obligation to the lecturers, not only for the

services so rendered, but for the amount of care and attention they devoted to the preparation of the series for publication. On their delivery, the Lectures were very much appreciated by the audiences to whom they were addressed; and their publication was only resolved on after numerous and pressing representations on the part of those interested in the subjects discussed.

Corporation Galleries,
Glasgow, *1st July, 1881.*

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## *APPENDIX.*

# ON SOME RESULTS OF RECENT IMPROVEMENTS IN NAVAL ARCHITECTURE.

By WM. PEARCE, Esq., of Messrs. John Elder & Co.

*ON WEDNESDAY, 19th JANUARY, 1881.*

It is impossible, within the necessarily limited time during which I am to have the privilege of addressing you, to enter into anything like a lengthened detail of the results of recent improvements in naval architecture, in which term I, of course, include marine engineering. I propose, therefore, to confine my remarks to the leading features which present themselves in a retrospect of the last five-and-twenty years.

This leads us back to the close of the first decade of the free-trade policy inaugurated by the late Sir Robert Peel—a policy which had, even then, given an impetus to the interchange among the nations of the varied productions of the earth and of the industry of man, culminating at the present time in a carrying trade as vast as it is beneficent to mankind.

It takes us back to the close of the Crimean War—a war which showed us our deficiency in ocean transport, and gave the first great impulse to the construction of first-class iron screw-steamers. The fruits of this were reaped by the nation in the promptitude with which, a couple of years later, we were able to respond to the cry for help which came to us from our countrymen in India. Since then, with the aid of our magnificent mercantile steam marine, we have been enabled to make the power of this country felt, wherever our honour or our interests have been attacked, with a celerity

which has made our small but splendid army practically ubiquitous.

In 1856 iron had asserted its supremacy over wood as a material for the construction of steamers, and the screw had likewise to a very large extent superseded the paddle. It was not, however, until some half-dozen years later that the Lords of the Admiralty consented to sanction the use of the screw by the Cunard Company in their splendidly-conducted mail service across the Atlantic. The "Scotia," launched in 1861, was the last paddle-steamer built for this Company.

In 1857 there was launched into the Thames the "Great Eastern," the greatest ship ever built, and the greatest failure financially. This steamer was constructed of iron, with the avowed object of carrying passengers comfortably and merchandise economically, but unhappily the paddle and the screw were combined as propelling powers, and the machinery used for driving these was of the ordinary type of low-pressure engines, involving an enormous consumption of fuel without adequate results. Had Mr. Brunel adopted the principle of the compound engine, the fate of the great ship and the finances of her shareholders might have been very different. Both screw and paddle laboured under the very serious disadvantage of being worked by low-pressure steam and the ordinary condensing engine, a disadvantage which made a long voyage, such as hence to Australia, under steam only, practically an impossibility. The main body of the ship was occupied by engines and boilers, and the greater part of the remainder was filled up with coals.

Messrs. Randolph, Elder, & Co. had, so early as 1854, adapted the compound principle to marine engines, the "Brandon" having been the first vessel in which they were fitted; the steam pressure of the "Brandon" was limited to 42 lbs. Later on, a pressure of 60 lbs. was carried, and this, as you are aware, has since been successfully increased to 70, 80, and even 100 lbs., the relative dimensions of the cylinders being altered accordingly.

A little later, the surface condenser was added, circular multitubular boilers were brought into use, and the com-

pound engine then became a machine which has revolutionised the carrying trade of the world.

In spite of the splendid success of the compound engine and surface condenser, the great steamship companies and shipowners generally were very slow to adopt it. The Pacific Steam Navigation Company was by many years the first to do so, having commenced as early as 1856, when Messrs. Randolph, Elder, & Co. built for them the "Valparaiso" and the "Inca," followed in rapid succession by 47 other vessels, besides one now in hand, making in all 50 for that company by the firm I represent and their predecessors.

One or two private shipowners followed the example of the Pacific Steam Company in adopting the compound engine, but so wedded were the leading engineers of the day and the marine superintendents of the great companies to the old type of low-pressure engines, that for many years they continued to fit them on board steamships, to the serious loss of their owners. This loss can best be appreciated when it is considered that the old type of engine required from four to five pounds of coal for the development of each indicated horse-power, whereas the best type of the compound engine requires as little as one and three-quarter pounds to give the same result, while the boilers last about double the number of years they did with the low-pressure engines without the surface condenser. Nearly all, if not the whole, of the larger class of steamships so fitted have had their engines converted into compound engines, or have had entirely new machinery supplied to them, or have been transformed into sailing ships. It was not until about the year 1869 that the compound engine came into general use, and it was only in 1872 that the Cunard Company and the Peninsular and Oriental Company took it into favour, their eyes having been, no doubt, opened by the success of the fleet of steamers of the new type which the opening of the Suez Canal in 1869 brought into existence.

During the period we have had under consideration, many minor improvements have been made, both in the engine and ship departments, such as steam starting and reversing gear,

steel shafting, improved forms of propellers, steam windlasses, steam cranes and winches, and steam steering gear; and our eminent townsman Sir William Thomson has contributed not a little to safe navigation by his improvements in the compass.

Very recently we have seen steel brought into competition with iron as a material for the construction of hulls, and also for boilers, especially in cases where ability to carry heavy cargoes requires to be combined with light draught of water.

Whether steel will materially encroach on the employment of iron will depend, to a very large extent, on the skill and care of the steel manufacturers, in producing an article of equal and sufficient purity, strength, and power of endurance, at a moderate cost.

A few figures will give you an idea of the results of the improvements to which I have alluded, and I shall take them, in the first place, from the greatest of our ocean highways—that between Liverpool and New York. After one or two unsuccessful attempts to establish a regular steam communication between this country and America, the Cunard Company, which we are proud to regard as a thoroughly Clyde concern, was formed in 1840, and has ever since kept well to the front. Fortunately for them, as well as for the cause of progress, they have not had it all to themselves, and have been compelled, by keen competition, to keep up with the times. Their first steamers were under contract to go at a speed of 8½ knots per hour; they indicated 740 horsepower, and consumed 4 7-10 lbs. of coal per horse-power. The speed and power were increased from time to time, and when the Americans put on the Collins Line it was found necessary to step out, and put on steamers which went 12 to 12½ knots, indicating 2,000 horse-power, and consuming a fraction under 4 lbs. of coal per I.H.P. These steamers made the passage on an average in twelve days and nine hours outwards, and eleven days eleven hours homewards; but the Collins Line averaged only eleven days eight hours outwards, and ten days twenty-three hours homewards, and the "Persia," and others of her class, had consequently to be put on to compete successfully with the American line.

The "Persia" was an iron paddle-steamer, built in Glasgow in 1856, and was the best type of a vessel of her description of her day. She performed her voyage between Queenstown and New York on an average in 10½ days. She was fitted with side-lever engines indicating 3,600 horse-power, and consuming 3 7-10 lbs. of coal per I.H.P. She attained an average speed of 12 9-10 knots, and consumed 150 tons of coals per day. The "Gallia," belonging to the same company, was built on the Clyde in 1879, and was fitted with engines on the compound principle, indicating 5,000 H.P., and consuming only 97 tons of coals per day. Her fastest passage was accomplished in 7 days 21 hours, and her average speed may be fairly taken at 15½ knots. The engines, boilers, and bunkers of the "Persia" occupied so much space and immersed her floats so deeply that she took no heavy cargo whatever, but besides passengers, she had always about 800 tons measurement of light goods, equal to about 250 tons weight. To obtain this room great competition existed, and the freight of £4 per 40 feet was readily paid, or about £10 per ton weight. The "Gallia" carries, besides her passengers, fuel, stores, &c., 2,000 tons measurement, or 1,700 tons weight of cargo, for which 20s. is considered a fair rate, and is competed for. Consequently, the "Persia" burned on her voyage 6 1-3 tons of coal for every ton of cargo she carried, while the "Gallia" burns something less than half-a-ton of coal for every ton of cargo she delivers, although she carries it two-and-a-half knots an hour faster.

The last comparison has been made between two vessels of the Cunard Company—a paddle and a screw. I shall now compare the "Pereire," which I designed and built at the yard of the late firm of Robert Napier & Sons in 1865, with the "Arizona," designed and built by my firm in 1879. The "Pereire" was a screw-steamer built of iron, and fitted with engines of the ordinary description, indicating 3,300 horse-power, and consuming 110 tons of coal per day, and steamed at the rate of 14¼ knots on her voyage. Whilst the total weight of the "Pereire," as she proceeded to sea, was no less than 4,944 tons, all the cargo she could carry was

only 640 tons dead-weight; so that to carry each ton of cargo from Havre to New York she consumed 1⅛ tons of coal. The "Arizona" indicates 6,000 horse-power, and consumes 1¾ lbs. of coal per indicated horse-power, or about the same amount of coal per day as the "Pereire." She attained a speed of 17¼ knots on the measured mile, and carries, in addition to her coal and her passengers, 3,400 tons weight of cargo, and when fully laden steams steadily at the rate of 16¼ knots an hour. She thus burns about 5 cwt. of coal for every ton of cargo she carries, and carries it two knots an hour faster than the "Pereire" did in her day. The "Arizona's" quickest passage was accomplished in seven days and eight hours, and is the fastest yet recorded.

Steam communication with Australia and New Zealand, until the improvements I have indicated, appeared to be financially impracticable; it has now been established on a sure basis. Not only are there two subsidised mail routes—the one by the Suez Canal, the other *via* San Francisco—but the Orient Company have established a direct unsubsidised and independent service, going out *via* the Cape of Good Hope, and returning *via* the Suez Canal, delivering letters 10 or 12 days quicker than the older subsidised lines. The "Orient" on her last trip delivered her Adelaide letters in London in 31 days.

On the great Atlantic road fresh preparations are being made for the struggle for the first place in safety, comfort, and speed, and it is more than probable that we shall, before the end of the current year, see the voyage between New York and Queenstown made in a little over six days.

Great as have been the improvements made during the last 25 years, their results should only incite naval architects and engineers to further efforts to improve not only the machinery, but the form of the hull itself. Until quite recently all attempts to improve the form of the hull ran pretty much in one groove, if we may except the twin ship, the cigar ship, and one or two others.

A few years ago the Admiralty constructed, at Torquay, a basin for the purpose of making experiments in hydrodyna-

mics, fitted up an establishment there, and placed it under the care of that talented man, the late Mr. William Froude, who invented and constructed all the requisite delicate machinery. Here, in a few weeks, more true knowledge of the resistance due to special forms can be acquired than in a whole lifetime of costly experiments at sea.

A similar establishment was inaugurated at the Royal Dockyard at Amsterdam, under the superintendence of my friend Dr. Tidemann. I am quite aware that when it became known that my firm had undertaken to construct the "Livadia" for the Russian Imperial Government, in accordance with the designs of his Excellency Admiral Popoff, and that we had guaranteed to propel her, with engines of a specified weight and power, at least fourteen knots an hour, with the provision that in case of failure, the Government was not obliged to take the vessel, many of my friends shook their heads mournfully, and thought I was a very rash man, ten knots being the highest speed they allowed to be possible with such a form of vessel.

Before I signed the contract for the "Livadia," a model of her form had been for several months under the care of Dr. Tidemann at the Royal Dockyard at Amsterdam, and a series of carefully-conducted experiments had made it an absolute certainty that, with proper machinery, a speed of at least 15 knots would be attained. The average speed actually got was considerably over this, her engines having given out greater power than engines of the same size had usually accomplished. It is a fact which may be worthy of notice that these engines gave out a mean power of 12,354 I.H.P., the total weight of engines, boilers, and water being 1,370 tons, that is, upwards of 9 horse-power for every ton of weight.

Seeing that the design of the "Livadia" is a greater departure from the ordinary type of vessels than any that has hitherto been built, and that a greater interest has been taken in her than in any other in modern times, if you have not already heard more of her than you care to do, I shall be glad to give you some hitherto unpublished details concerning her,

more particularly with reference to her behaviour while crossing the Bay of Biscay.

To those who did not watch the building of the yacht, I would like to explain that it consisted of a structure in a turbot-shaped form, with a superstructure containing the Imperial apartments and the accommodation for the suite and the crew. This turbot-shaped portion was built in the following manner:—An oval-shaped vessel was first laid down, with a double bottom and vertical sides, about 190 feet in length and 120 feet in width. The vertical sides were about 20 feet in height. This is, in point of fact, the ship proper, into which are fitted the engines, boilers, pumping arrangements, coal bunkers, electrical engines, magazines, stores, &c. —in short, everything required for locomotion and safety.

This oval-shaped vessel having been built, every addition made to it had for its object an external form to suit the speed and stability required, and to adapt it to the comfort and convenience of its Imperial proprietor. On the outside of the oval were built frames attached to its vertical sides, to form an outside belting, and thus to give the shape which we know as the edge of the turbot. This belting was about 15 feet in breadth all round the vessel, and was divided into 37 watertight cells, by means of longitudinal and transverse bulkheads, and was designed solely to give shape to the ship, and to form a protecting covering, so that nothing could reach her skin without first breaking through two thicknesses of plates. The cells of this belting were not intended to carry coals, cargo, or in fact anything. If every one of the 37 had been filled with water, it would have only increased the draft 22 inches, and the vessel would not only have been perfectly seaworthy, but she would have been much steadier in the rough weather she encountered in the Bay of Biscay.

After the trials, as to speed and power, which took place on the Clyde, the satisfactory results of which are well known to all, the "Livadia" steamed to Brest. Throughout her voyage the weather was fine, the vessel perfectly steady, and there was an entire absence of vibration. Shortly after leaving Brest, however, to cross the Bay of Biscay, a storm arose,

which increased to a gale of extraordinary violence. In a very few hours a very heavy cross sea got up, and huge waves dashed against each other or broke against the ship with great fury.

Although designed to sail on the more placid summer waters of the Black Sea, the "Livadia" behaved nobly in the gale, and it was with no slight feelings of gratification that the Grand Duke Constantine and his guests, as well as the designer, and I may also add the builder, of the yacht, witnessed the manner in which she held her own. The fierce waves dashed against her, but, thanks to her peculiar form, they dashed in vain, not one reaching the structure on her deck, or causing any inconvenience to those on it beyond the reception of an occasional shower of spray.

The yacht was marvellously steady even at the height of the gale. I give you the official figures on this point. In transverse rolling the greatest angle of heel on each side was $2\frac{1}{2}$ degrees. In longitudinal pitching the maximum inclination at the stern was 5 degrees, and at the bow 4 degrees.

The height of the waves was judged by Admiral Sir Houston Stewart, Sir Edward J. Reed, and other experienced nautical men, to be from 20 to 25 feet. The waves never reached the boats, the keels of which were 22 feet above the load line; even the broken water never reached nearer than a foot from them. The peculiar receding form of the upper portion of the turbot, and the salient shape of the superstructure, appeared to divide the wave against itself, and to give an amount of immunity to the ship, which can scarcely be understood by those who were not actual observers.

The clinometer showed that the rolls were not continuous, but were subdivided into several parts; the angular motion would cease for a moment, and then again would proceed. Occasionally a tendency towards a return motion could be perceived during an oscillation. In a smaller degree a similar tendency was at times observed in the pitching motion.

A very remarkable circumstance was observed by the Grand Duke during this gale. The aneroid in his apartment,

a very sensitive instrument made by Dent, moved to one side when the stern was being lifted, and to the reverse side when it was being depressed. The maximum deflection while lifting represented a rise of 17¾ feet, and while descending 10¾ feet, and these figures correspond to what we would expect to find when we calculate the leverage of oscillation.

The "Livadia" kept her course, notwithstanding her shallowness, quite as well as vessels of the usual draught of water. In doing so she had the advantage of possessing three propellers, wrought by three independent engines. During the gale she required only one man at the wheel. Her propellers never emerged from the water, and there was, consequently, no racing of the engines.

During the height of the gale the meals were served with the same regularity and composure as during the fine weather between Clyde and Brest; the tall candelabra were placed on the table as usual; no extra precautions were taken to secure the elegant and costly ornaments of the Imperial apartments, nothing was done in the dining saloons to prevent breakage of furniture or dishes, and, as a matter of fact, not a plate, not a glass, was broken; in the sleeping-rooms even the ivory-handled brushes bade no good-bye to the marble slabs on which they were laid.

There were only two drawbacks to all this comfort. The first was that the yacht was very much undermanned, both on deck and in the engine-room, and the crew were very much exhausted after their long battle with the gale; and the other was that as one huge wave receded from under the bow of the ship, the descending flat bottom forward was met by the next fierce billow with a blow that, whilst it could not injure the vessel proper, shook the superstructure, which had been designed of a light character and for far different treatment.

No one, however, suspected that any injury had been done, until after her arrival at Ferrol, which was the port it was considered most suitable to make for after reaching Cape Finisterre, in consequence of the prostration of the crew. On making a thorough examination at Ferrol, it was dis-

covered that two of the 37 cells on the external rim of the turbot had suffered, and contained water. These cells were 16 feet in length, 6 feet in breadth, and the depth of water was about 7 feet—being the draught of water of the ship. This will convey to you an idea of the trifling character of the injury. Two plates in these cells had been bulged in, and appeared as if they had struck against some solid substance. As wreckage had been seen, it was not unnatural to suppose that the ship had struck some of it. I am not sure, however, that the heavy blows of the sea against structures so light as those outer cells were designed to be may not have caused the damage. As I have already pointed out, they might all have been filled with water and yet added to the seaworthiness of the vessel. You may consequently judge of my amazement, on my return to the land of newspapers, to learn that this trifling injury had been described as the reason for the "Livadia's" remaining at Ferrol until the spring. During the time we were at Ferrol we were daily expecting to receive orders to fill up with coals and to leave for the Black Sea.

After steaming round to Corunna, however, to land the Grand Duke and his party, the vessel was ordered to return to Ferrol, and there lie up for the winter. I was the guest of His Imperial Highness the Grand Duke Constantine, and it was not for me to inquire into the reasons for detaining the vessel; but I may tell you that the port of Ferrol is one of the finest in the world. It is completely land-locked; and the floating basin of the Royal Arsenal is not only very extensive, but exceptionally safe, and thoroughly well guarded by sentinels, so that the "Livadia" lies there in greater security from accident or from the threatened attacks of Nihilists than even in Sebastopol. It also appears that His Majesty the Emperor did not require the yacht during the winter, and that the dock at Sebastopol was not ready to receive her.

It is most unfortunate for the progress of naval architecture that this incident has occurred, because it has given an opportunity to many enemies of progress to throw

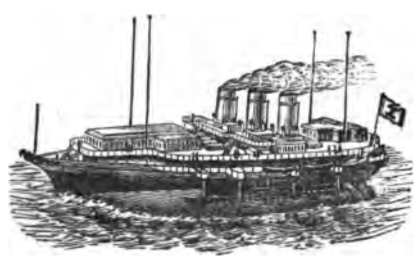
doubts on a design which really possesses some very great merits.

No armour-clad should be designed without the adoption of some of the qualities of the "Livadia." I do not refer to the shallowness of her draught, as on that matter I never did agree with Admiral Popoff; but on the question of the great breadth and receding sides, I am certain, we have learned much from the "Livadia," and we must introduce these qualities into the design of every ship for which we desire a steady platform.

Allow me, in conclusion, to draw your attention to the necessity that exists for such establishments as those at Torquay and Amsterdam being brought within easy reach of the Clyde builders and engineers. Looking to the fact that the nation, in the long-run, reaps the benefit of all improvements in naval construction, and that so many of these emanate from this river, we might well ask Government to assist us; but we have always, in this part of the country, been partial to self-help, which is the best help of all. I hope this matter will be warmly taken up, and shall be only too glad to do all in my power to aid in giving it a start.

Such an exhibition as that we now have the advantage of inspecting reflects the highest credit on the committee that organised it. The great number of visitors shows how generally the profession it illustrates meets with the sympathy of the public, and truly the public may well be interested, when they reflect on the vast extent to which they are dependent on naval architecture for the necessaries and luxuries of life. During last year we had 180 millions worth conveyed to us from foreign countries. Our steam merchant fleet had increased from 1,350 steamers in 1850, measuring 187,000 tons, and 2,357 steamers in 1860, measuring 500,000 tons, to 6,629 steamers in 1879, measuring 2,730,000 tons, or one million of tons more than all the rest of the world put together. We carry not only the bulk of our own vast commerce, but we assist every nation that possesses a sea-board to carry theirs; we ask no protection, no bounty, but we do

ask that our Government will do their utmost to prevent our trade from being insidiously attacked by foreign Governments granting bounties, in order to foster their merchant marine; not that we need fear, in the long-run, any fostered industry—competition is the very soul of true work; but we may in the immediate future be exposed to undue and unfair rivalry.



# LAYING AND REPAIRING SUBMARINE TELEGRAPH CABLES.

By ANDREW JAMIESON, C.E.,
**Principal of the College of Science and Arts, Glasgow,**
**Late Electrician to the Eastern Telegraph Company, Limited.**

*ON FRIDAY, 28th JANUARY, 1881.*

I HAVE chosen as the subject of this evening's lecture "The Laying and Repairing of Submarine Telegraph Cables," partly because I have been intimately connected with these operations for the last few years, partly on account of the apparatus exhibited here by Sir James Anderson (Catalogue, 702-710), and partly from the fact that I believe it will prove new as well as interesting. The subject-matter of the lecture will be discussed under the following heads :—

1. The great commercial and political importance of submarine telegraphy.

2. The facilities offered for telegraphic communication with almost all parts of the world.

3. The component parts of a cable, why they have been selected, and how they are put together.

4. The general arrangement of a telegraph steamer.

5. The preliminary survey previous to laying a cable, with a description of Sir William Thomson's sounding machines.

6. The mode of laying cables.

7. A popular explanation of how faults occur, and how they are localised.

8. The repairing of a faulty cable, with the difficulties encountered, and how they are overcome (including a description of my patent grapnel for catching cables).

First, the commercial importance of submarine telegraphy

is at once apparent when you understand that at the present moment there is £30,000,000 worth of cables lying at the bottom of the ocean, of which £26,000,000 is owned by seventeen private companies.

Of this, the Anglo-American Company owns £8,000,000, the Eastern and South African £6,250,000, the Eastern Extension about £3,000,000, and the various other companies own smaller amounts, according to the lengths of cables and types employed. These large sums of money have been almost entirely subscribed by private investors, and many of the companies return a very fair and secure dividend on their capital. The political importance arises principally from the fact of Governments (and more especially in the case of the British Government) being able to issue orders to their fleets and armies from head-quarters, as well as to arrange matters connected with colonies and different Governments, in a manner, and in a space of time, that would have been utterly impossible a few years ago without the aid of telegraph cables. This importance has been particularly noticeable during the recent troubles in South Africa, the Government here having been in constant communication with the head-quarters of the army in Natal.

I will now point out to you the routes of the chief cable companies by means of this large chart, which Mr. Mavor assisted me in getting up for the lecture. (See Telegraphic Chart, kindly presented by Sir James Anderson, managing director of the Eastern and South African Cable Companies.)

Let us start from Valentia in Ireland, with which Glasgow is in telegraphic communication, and go westwards by the Anglo-American Company's cables to Newfoundland, and from thence to New York, which is in telegraphic communication by land lines with the whole of the North American Continent, including San Francisco. This large company has from first to last had seven transatlantic cables laid between Ireland and America, viz.:—the 1858, 1865-66, 1866, 1869, 1873, 1875, and 1880. The first four are now unworkable or broken. The last one was completed on the 21st of August last year, and only took twelve days to lay from Heart's Con-

tent (Newfoundland) to Ireland—the quickest, and, perhaps, most successfully laid of all the Atlantic cables, for it is reported that not a single hitch occurred during the operation, to such a pitch of perfection have the engineers, electricians, and captains of the Telegraph Construction and Maintenance Company arrived, by continued practice and careful selection of the most approved appliances. This company has laid all the seven "Anglo" cables, besides more than half the other cables in the world.

This is a very different story from the early trials in 1857, and 1865-66, when submarine telegraphy was in its infancy. If any of you are interested in such operations, you cannot do better than read the book on the 1865-66 expedition by Dr. Russell—*The Times* Correspondent—where you will find the whole matter most lucidly and graphically described. With the Direct United States cable and the new French Atlantic cable laid last year, we have, in all, nine cables that have been put down between Europe and America. Considerable rivalry has existed of late between the French Atlantic, the "Anglo," and Direct United States Companies, in consequence of which the tariff was reduced for some time to sixpence a word (a rate which could never pay); but by some curious "mesmerism" these new companies, as they start up, are seemingly silenced or bought over by the more powerful and moneyed "Anglo" Company. We have lately heard of the Yankees starting a couple of cables for themselves under the wing of Mr. Gould; probably they will fare no better than the French and Direct United States Companies have done. We shall now turn eastward, and trace the routes of the Eastern and Eastern Extension Companies to India, China and Australia, &c. It may be worth mentioning that Mr John Pender, M.P., is at the head of these companies, along with Sir James Anderson, another well-known and eminent Scotchman, who commanded the "Great Eastern" during the 1865-66 expeditions.

You see traced on the large Mercator's chart before you the route from London to India by Porthcurnow, Lisbon, Gibraltar, Malta, Alexandria, Suez, Aden, Bombay, Madras,

to Singapore, thence onwards to Shanghai and Japan, to Port Darwin, Melbourne, Sydney, and New Zealand; also from Aden, *via* Zanzibar, to Natal and Cape Colony. The duplicate and triplicate routes are also marked, whereby you will at once see the prudent foresight shown in thus providing separate routes, guarding against possible unfavourable contingencies arising from breakages or wars, and thereby allowing the Eastern companies to carry on business to the satisfaction of the public.

There is a perfect net-work of cables in the Levant, thence reaching away up through the Dardanelles, past Constantinople, and up the Bosphorus to Odessa in the Black Sea—all under the Eastern companies. I was electrician in charge of the laying of all the cables connecting Besika Bay with Lampsaki, Tenedos, Salonica, and Chios, at the time of the Russo-Turkish War; and a most interesting and enjoyable expedition it was, for we had an opportunity of seeing and hearing of many circumstances which people at home only learned of second-hand through the daily papers.

I will just run hurriedly over the route of the Great Northern Telegraph Company (see chart) through Russia to China, and the Brazilian Submarine Telegraph Company from Lisbon to Pernambuco *via* Madeira and St. Vincent, as well as the Western and Brazilian Telegraph Company, whose cables extend from Para, on one of the mouths of the great river Amazon, *via* Pernambuco, Bahia, Rio de Janeiro, Santos, Santa Catherina, Rio Grande do Sul, to Monte Video. I first made my acquaintance with foreign countries by visiting all those towns on the Brazilian coast in connection with the laying and maintenance of the cables there, having been sent out by your townsman, Sir William Thomson and Professor Fleeming Jenkin, the consulting engineers.

This finishes the long and more important foreign routes, and you will observe that it only requires a cable to be laid from San Francisco or Vancouver's Island to Japan in order to complete the electric girdle round the earth with Britain's hands on the buckle.

It is almost needless, after what I have said, to expatiate

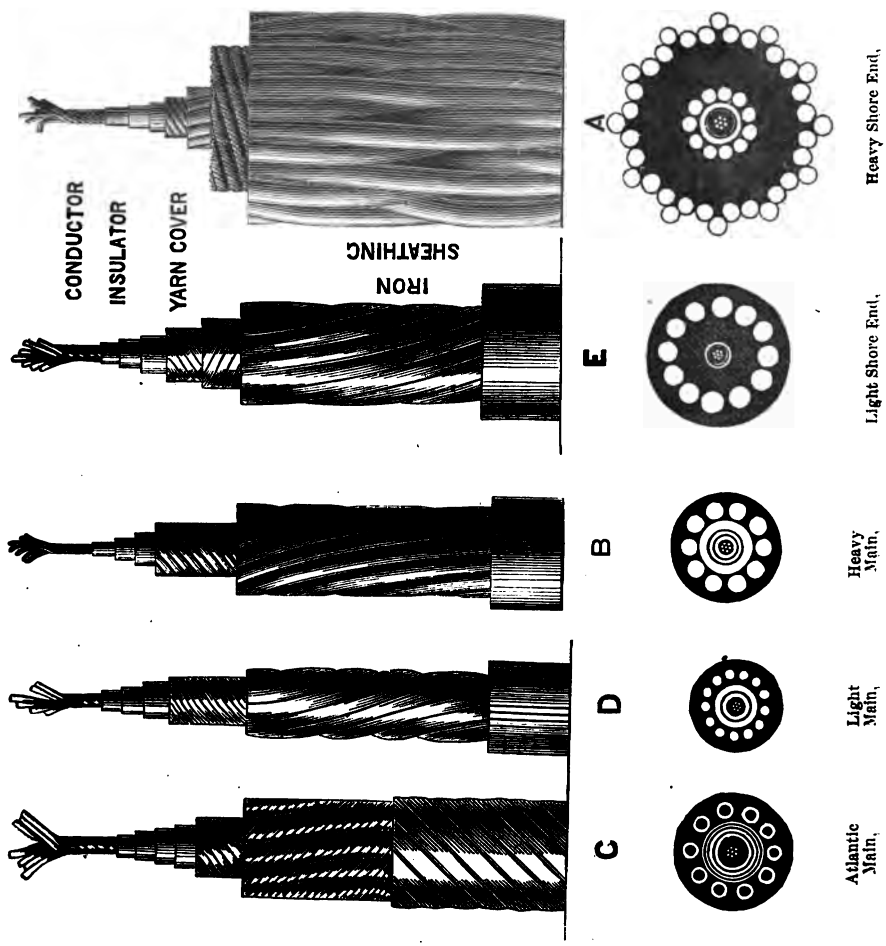
further on the great commercial and political importance to Great Britain in thus being able to communicate with her colonies, and Englishmen richly deserve *kudos* for their enterprise, for nine-tenths of all the vast net-work of this submarine system has emanated from the banks of the Thames, and the head-quarters of all these large companies are to be found in and around that busy centre of commerce, Old Broad Street.

We now come to inquire of what and how a cable is composed. Here is a good specimen. [Showing it.] In the centre we have the conductor of the electricity, generally composed of seven copper wires twisted together into a strand, in a similar manner to that in which an ordinary piece of whip cord is made, and by a machine not unlike that shown in Fig. 3 for sheathing the cable. Here before you, on this table, is a very neat machine for stranding copper wires, kindly lent to me for the lecture by Messrs. William Barton & Co., 153 Scotland Street, from their exhibit downstairs (Catalogue, 670). The reason that copper has been selected is this, that it has been found to be the best commercial conductor of electricity; and the object of making it up in a strand of wires instead of using a single wire arises from the fact that the combined sum of the small wires is stronger, *more pliable,* and *less liable to break,* than if it were composed of a single wire of the same area and conductivity; besides which, should one, two, or even three of the small wires break at any point, the remaining wires are still available for conducting the electricity, whereas a single wire, once broken, is of no further use until repaired.

The copper strand which I now show you will bear a strain of 200 lbs. before breaking.

Now, this simple conductor of copper wires is all that would be required for a submarine cable, were it not for the subtle nature of the electric force, which, unfortunately for the expense of cables, takes every possible opportunity of dissipating, or running "*to earth,*" as it is technically termed; for before it had got a few feet, or even inches, the current would be entirely lost in the sea. It has, therefore, to be

*Fig. 1.*


CONDUCTOR
INSULATOR
YARN COVER
IRON SHEATHING
A
Heavy Shore End,
E
Light Shore End,
B
Heavy Main,
D
Light Main,
C
Atlantic Main,

covered with an *insulator*, a substance capable of preventing this taking place.

*All substances offer resistance* to the passage of electricity, some, fortunately, very little, others a great deal. Those which offer a small resistance are termed conductors, amongst which are the metals, copper, silver, iron, &c., and which are, therefore, selected for the purpose; whilst gutta-percha, india-rubber, glass, ebonite, dry wood, and such-like, offer a great resistance—many million times that of the metals just mentioned—for the same sectional area and length. Advantage is taken of this well-known fact to coat the copper conductor with layers of gutta-percha or india-rubber.

Gutta-percha has stood the test of time better than any other substance, being found as good as the day it was first made after thirty years, *if continually kept under water.* The combined gutta-percha and conductor constitute the "*core*" of the cable. The diagram before you (Fig. 2) shows how the machinery is arranged for coating the wire with

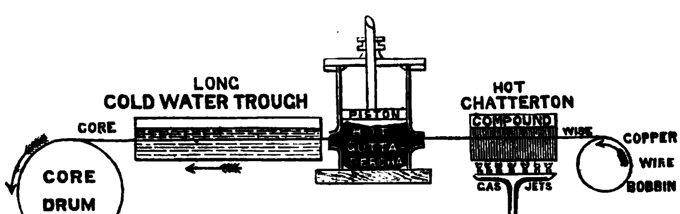



*Fig. 2.*

gutta-percha. First, we have the wire, which is covered with a thin coating of Chatterton, then gutta-percha, and each successive coating receives a thin layer of Chatterton's compound (a kind of glue, consisting of Stockholm tar 1 part, resin 1 part, and gutta-percha 3 parts), in order that there should be perfect adherence between the layers, and the whole form a solid coating.

Now, this core would, in every electrical sense, suffice as a perfect cable for transmitting messages; but practical reasons, arising from the soft and delicate nature of the insulator, render it necessary that it should be protected with some-

thing harder and stronger; for, as it passed from the ship into the sea, and during its existence there, it would be subjected to so much rough usage that it would shortly be destroyed. The slightest puncture from a fine needle is sufficient to affect the insulation very seriously, and in the case of a very long cable a fault arising from this cause would, in time, prevent the working, unless repaired or sealed up.

The core is, therefore, covered with a serving of tanned yarn, in order to form a *soft bed*, upon which the iron wires may rest; and this is done by passing it through the hollow spindle of a revolving face plate containing bobbins of yarn, which are spun upon the core as it passes along. It is then carefully coiled in small water-tight iron tanks, and covered with water, and carefully tested electrically previous to being passed through the sheathing machine (Fig. 3).

This machine, with its 10 or 12 bobbins (F) filled with iron or steel wires of the desired diameter for the kind of cable required, revolves in a vertical plane, while the core, C, is pulled through in a horizontal straight line. These galvanised iron or steel wires are laid or twisted on in a spiral form, and they fit or butt closely against each other, as seen in Fig. 1, types E, B, and D. The sheathed cable then passes direct from the draw-off drum, X (Fig 3), to a trough containing Clark's compound, quite hot (5 of tar, 65 mineral pitch, and 30 of silica); then through the centre of a similar machine to the first yarn-serving machine, where it gets covered with tarred Manilla yarn; then through another trough of Clark's compound, also hot, and on to the large cylindrical water-tight tanks, where it gets swabbed down with silica wash, to prevent the coils and layers of cable sticking to each other. The machine shown at the lecture was kindly lent by W. Barton & Co., of 153 South Scotland Street, Glasgow.

Here are a set of specimens of the different types of cables used in the Platino-Brazilian cable, which were presented to me by Messrs. Siemens Brothers while at their works. [See Fig. 1.] These will serve to illustrate the object of the different sections required in making a cable. This is called

type A, or "heavy shore end," 18 tons to the knot, used in very shallow waters (under 30 fms.) where rocks exist, and where the cable is likely to be subjected to the chafing action of tides and currents.

FACTORY SHEATHING MACHINE.

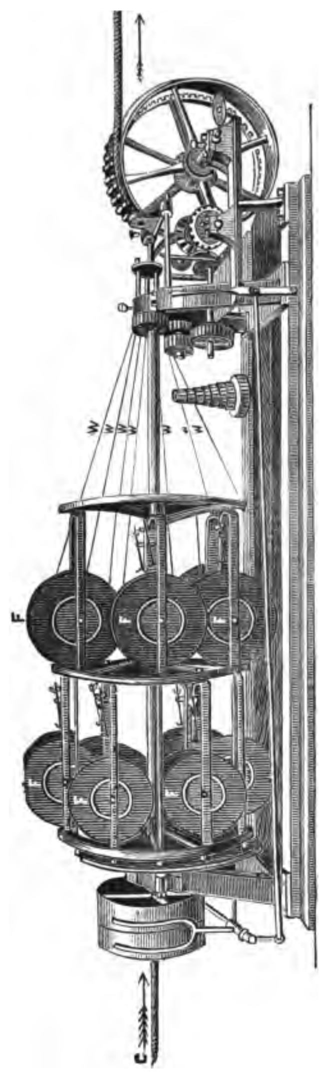



*Fig. 3.*

Here is a lighter form of "shore end," weighing about 6 tons to the knot, called type E, used in waters up to 50 or 60 fms., where rocks are not so prevalent, and where the action of the tides and currents is not likely to be so strong as to require the heavier type just shown to you.

Next comes type B, or what is termed "intermediate cable," $3\frac{1}{2}$ tons to the knot, used in depths from 50 to 250 fms.; a strong, serviceable cable, with, as you will observe, 10 iron wires, well galvanised, of No. 6 Birmingham wire gauge.

Here is type D, a much lighter cable or "deep sea," of only $1\frac{1}{2}$ tons to the mile, used in depths varying from 250 fms. to 1,000 fms., and capable of bearing a strain of $3\frac{1}{2}$ to 4 tons. Here is type C, "Atlantic deep sea," of nearly the same weight in air as type D (just shown to you), but specifically much lighter in water. Its great feature being combined lightness and strength, it is used for depths varying from 800 fms. to 2,000 and over. This cable is capable of bearing its own weight on the bight in $2\frac{1}{2}$ miles depth *when new*, and I shall have to refer to it further on in the case of a repair lately effected in 2,000 fms. water, off the coast of Spain, by the s.s. "Chiltern," after having been down ten years—the greatest feat yet done in cable repairing by a single ship. Most of you will, no doubt, have noticed a specimen of this picked-up cable in the exhibition below, kindly sent to me by Sir James Anderson, of which he is justly proud, for if it had not been for his persistent and hopeful belief in the possibility of such repairs, backed up by the skill and perseverance of his electricians and captains, such a feat would not, in all probability, have been accomplished for many years to come. The sheathing is composed of steel, or homogeneous iron wire, of great strength, bearing a strain of 50 tons to the square inch, each wire being previously covered with tanned Manilla yarn. The deep sea, Atlantic, Bay of Biscay, and Indian Ocean cables are made of this type, and they have proved very serviceable indeed. The Clark's compound and yarn (or outer tape serving) are simply put on to render the life of the cable longer by preventing rusting and decay of the iron wires.

The cable having now been made in the factory, and the cable ship fitted up, she is brought alongside the wharf opposite to the factory, and transportation takes place from the factory to the cable ship.

I should here mention that a thorough and constant system of electrical testing is kept up during the whole process of manufacture and coiling from one tank to another, in order

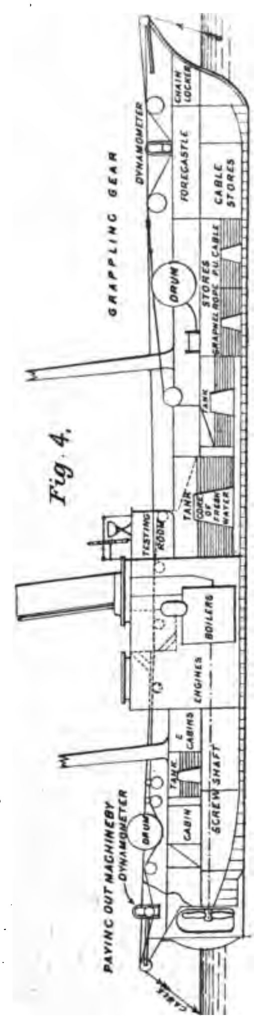



*Fig. 4.*

TELEGRAPH SHIP.

DESIGNED BY ANDREW JAMIESON.

Length, 230 feet.
Breadth, 32 ,,
Depth, 17 ,,

Scale, $\frac{1}{50}''$ = 1 foot.

Tonnage, 1,000 tons.
Indicated H.P., 1,100.
Speed, 13·5 knots.

to ascertain the electrical values of the cable, as well as to detect, upon the shortest possible warning, the appearance of a fault.

We now come to the fourth division of our lecture, or "The General Arrangement of a Telegraph Steamer."

On the wall before you is a large longitudinal section of a steamer having all the latest improvements.—See Fig. 4.

The vessel is designed to be 1000 tons, and 1100 indicated horse-power, and capable of steaming at 13½ knots an hour. It is very necessary to have a fast smart steamer when long sections of cable are to be looked after, as a fault may break out several thousand miles away from the place where the steamer may be lying, and "*time means money*" in such cases, where it is very desirable to be on the spot as soon as possible.

The size and form of vessel before you is suitable not only for holding and paying out a new cable of 300 miles in length, but of repairing one in any depth up to two miles, unaided by other vessels. Let us commence our description with the large main tank (forward of the boilers), and follow the paying-out machinery aft. This tank is circular, and water-tight right up to the spar deck, with a water-tight manhole, which may be opened when necessary so as to pass cable ends through between decks. In the centre is a water-tight wrought-iron cone, suitable for keeping lengths of stripped cable or "core," or, if going a long voyage, fresh water. The feed and discharge pipes from this, as well as all the tanks, are connected with a special donkey pumping-engine situated in the engine-room, and under the management of the ship's engineers (deck pumps driven by steam winches generating noise and requiring lengths of hose should be avoided). This tank is 30 feet in diameter and 15 feet deep, and capable of holding 200 miles of type D (see Fig. 1) without difficulty, and, therefore, occupies the main cable-carrying capacity of the ship. It is shown rather more than half full of cable, and the dotted lines indicate the cable as it passes through the eye of the tank, over the guide pulleys on deck, through the alley way to the jockey machinery, where any twist or ten-

dency to kink is taken out of it or straightened before taking three or four turns round the paying-out drum, after leaving which, it passes over a guide pulley underneath the dynamometer pulley (which is used to indicate the strain brought to bear upon the cable), and over the stern pulley into the sea. You observe another tank just forward of the saloon. This is used for holding "shore end," or the heavier type of cable, but it is handy for any kind that may come to hand. We shall now have a look at the forward or picking-up and repairing gear. As seen in the drawing, the full black line with the arrows indicates the direction of the cable as it is picked up over the bows of the vessel into No. 3 tank. Beginning at the bow sheaves (of which there may be two or three, some

DYNAMOMETER.

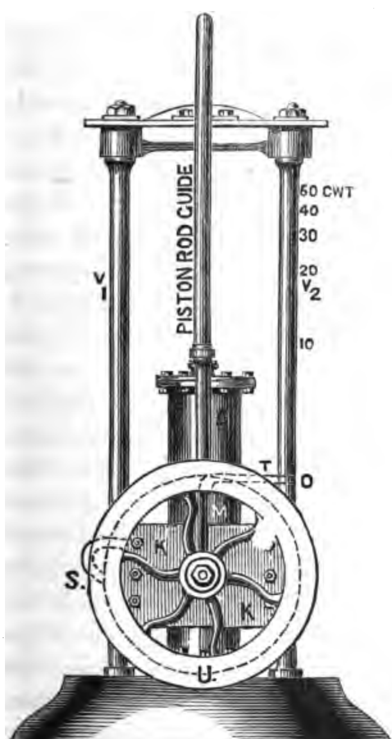



*Fig. 5*

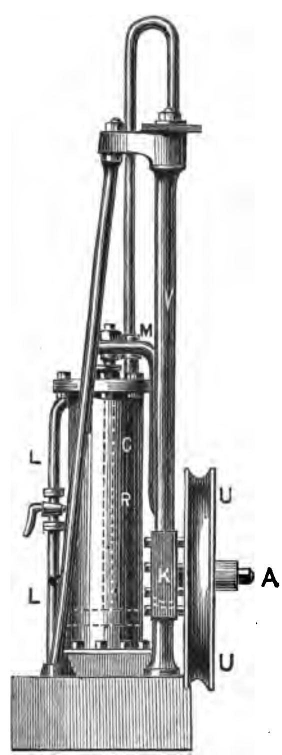



*Fig. 6.*

telegraph engineers preferring the one number and some the other), we pass on inboard to the dynamometer, which is placed midway between two guide pulleys, the one on the raised forecastle deck, and the other on the spar deck. This dynamometer, as in the case of the one aft, is for measuring the strain brought to bear upon the grapnel rope or cable. The raised forecastle deck is 40 feet long, with an extended platform close to the bow sheaves, and as this is large and not cramped it gives plenty of room for going about the rough and ready work which has to be carried on when getting a cable end on board or slipping a final splice. The top of the picking-up drum just appears about 6 inches above the spar deck, while the whole of the machinery, consisting of a pair of strong horizontal engines, is firmly fixed on the main deck. The engines receive steam from a special boiler (not shown), or from the main boilers, as desired, and the whole of the starting handles and brake levers for manipulating the compound right and left handed gear are so conveniently placed on the spar deck that one man, by watching the large dynamometer scale (which is marked with large figures on its aft as well as forward side) and the directions of the engineer or officer in charge, can manage them with ease. Suitable draw-off gear for pulling the cable when it has passed the picking-up drum into one or other of the tanks is fixed, but not shown. There are two shallow tanks, one for grapnel rope and the other for picked-up cable—or *vice versa,* in the case of a deep-water job. Forward of No. 3 tank is situated the chief cable store, as seen, beneath the forecastle, while there is a space forward for buoys and large grapnels. The space between decks is suitably arranged for the carpenter's bench, &c. The testing room is most conveniently situated above the large tank amidships, and there is a working chart-room above it, close to the forward steering wheel, while the light pilot bridge is above that again. A light narrow bridge connects the working chart-room and the raised forecastle deck, whereby those in charge can pass from the one place to the other, as well as watch and direct operations at any intermediate spot therefrom.

Let us suppose a ship properly equipped with such arrangement of tanks and machinery, fully found and manned, with efficient telegraph engineers, electricians, captain, and crew, ready to start on an expedition. Preparatory to laying the cable, however, a careful survey of the shores where the cable has to be landed, and particularly of the sea bottom between, must be taken. This is a point that was very much neglected in the early days of submarine telegraphy, and many companies now sadly repent this want of precaution, from the fact that their cables have broken and given out. You must understand clearly that the bottom of the sea has been found just as irregular as the land on which we live. There are as deep valleys and as high eminences below the surface of the ocean as there are above. I have myself measured a difference of depth of over 600 ft. in a distance little more than a ship's length, and taken soundings two miles deep, while only a few miles distant there was shallow water. Take a look at this sketch on the black board, and you will at once have an idea of the configuration of the sea bottom in some places. Fortunately for cable companies, it is not all irregular like this, for in the Mediterranean we took a line of soundings from Marseilles to Bona in Africa in the Eastern Telegraph Company's s.s. "Chiltern," for the purpose of determining what was the nature and configuration of the bottom, and found a beautiful easy incline, or slope, or descent, ten miles from Marseilles ranging from 1,000 to 1,745 fms., and then as gradual a rise on the other hand to Bona.

We did this by means of Sir William Thomson's excellent and practical large sounding machine, which I shall describe to you in a few minutes. Here you have before you his smaller machine, which he kindly lent me through Mr. White, of Sauchiehall Street, the well-known maker of his instruments.

This instrument is specially designed for taking soundings in shallow waters, up to 100 or 130 fms., without stopping the ship; in fact, going at full speed, 16 knots an hour, and, say, to 200 fms. It is found to be of the greatest possible use to captains making port in foggy or dirty weather, and

no ship should be without one, and more especially telegraph steamers, as they have to "potter" in all sorts of places near shore. The whole machine is placed in a water-tight trough, containing lime water, to prevent rusting of the steel pianoforte wire which is used. Then we have a small galvanised sheet-iron or steel drum, revolving truly on its bearings, supported by lignum vitæ brackets. The drum is one yard in circumference, but the tell-tale registers fathoms. It contains 300 fms. of best pianoforte wire, ·03 in. in diameter, weighing 1½ lbs. per 100 fms., and bearing a strain of 230 lbs. without breaking.

The wire used is therefore very light, strong, and of small area —the chief requisites for a good sounding-line. Attached to the end of the wire are three or four fathoms of cod line, and to the end of that a long sinker. A brass tube, containing a small glass one hermetically sealed at one end, is attached to the cod line about ten feet from the sinker.

It is well known that the pressure upon a body immersed in water is proportional to the depth to which it is sunk, so the air in the glass tube is compressed by "head of pressure," and the interior of the tube being coated with chromate of silver, which is soluble in salt water, chemical action takes place, thus leaving a mark in the tube proportional to the depth to which it has been sunk, which can easily be read off in fathoms by applying a suitably-graduated rule, which is supplied with each machine. There is one of the glass tubes coated internally with chromate of silver, and with both ends specially left open. You observe that when I put it into this long glass jar, containing salt water, and keeping my finger firmly pressed upon the upper end, upon lifting it out of the salt water it has only become discoloured or whitened for a very short distance—barely a quarter of an inch; but if I again dip it into the salt water, removing my finger from the upper end, you see the chromate of silver suffers decomposition by the salt water, and the discoloration almost instantaneously appears as far up the tube as it was dipped into the salt water, leaving a clear white line; and if we take this specially-made rule here and measure the distance from what

would be the sealed end in actual practice, we observe it agrees with that marked 55 fathoms. You see how simple a matter it is. The chemical action which actually takes place is this: The chlorine leaves the sodium of the common salt and combines with the silver, while the chromic acid and oxygen leave the silver and combine with the sodium. Thus chloride of silver, white and insoluble, remains on the glass in place of the orange-coloured chromate of silver lining as far up as the water has been forced into the tube, and the chromate of sodium dissolved in the water is expelled as the air expands when the tube is brought to the surface.

$$2NaCl + Ag_2CrO_3 = 2AgCl + Na_2CrO_3.$$

The machine before you (see Figs. 1, 2, 3) embodies all Sir William Thomson's latest improvements, and instead of the glass tube, he has designed a new form of depth-gauge; but before describing the machine and gauge in detail, we will show you practically how a sounding is taken with it, which is done by two men, under the superintendence of an officer. [The operation was gone through before the audience.]

Fig. 1 shows the machine with the small weight A resting on the long weight W, and the brake cord B slack, as it is when the wire is being wound in. To put on the brake, lift the long weight W by the hand rope E, and place the small weight A in the recess in the large weight, and then slack the hand rope again. While a sounding is being taken the long weight W is held up by the rope E, so as to allow the small weight A to hang freely. As soon as the sinker reaches the bottom the brake is put on by easing the rope E and allowing the weight W to be supported, by means of its jaws, on the small weight A. The whole weight of W should not be allowed to come suddenly on A, but it should be eased down gradually. If, when the whole weight of W is resting on A, the wire still continues to run out, the brakesman should press his hand down on the top of W until he stops the wheel.

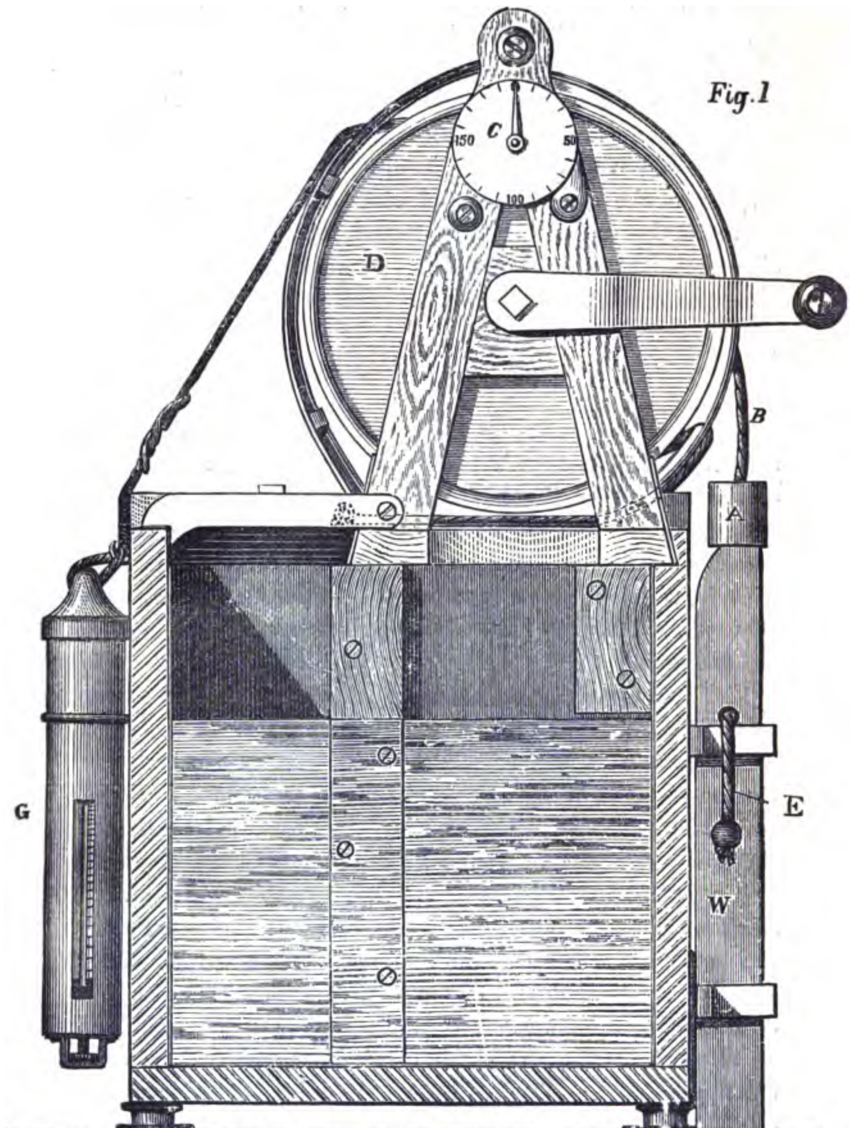


Fig. 1
C
150
50
100
D
B
A
E
W
G

Figs. 2 and 3 are drawings of the depth-gauge. Fig. 2 is the complete gauge, and Fig. 3 is a drawing showing the inside tube, *a*. Fig. 2 is the screw for screwing up the valve, *d*, against the edge of the three glass tubes, $g^1$, $g^2$, $g^3$. Before the gauge is allowed to go down it should be examined to see that there is no water in any of the tubes, and then the valve, *d*, should be closed by means of the screw, *a*. The inside tubes can be taken out of the case on unscrewing the top of the case, *c*. At *f* a small piece of the case is cut away to facilitate the getting of the tubes out. At the bottom of the brass tubes, $b^1$, $b^2$, Fig. 3, there is a piece of very fine strong cotton or linen cloth. If it becomes necessary to renew this, the tube must be heated gently to soften the wax on the screw of the brass tube, and the cap screwed off. A fresh piece of cloth can then be tied on and the cap screwed back to its original position and fixed with a little bees-wax or lard. If there is a difficulty in starting the cap, it may be done by binding a piece of twine twice round it and tightening it by pulling on the ends and pressing the brass

*Fig. 3.*

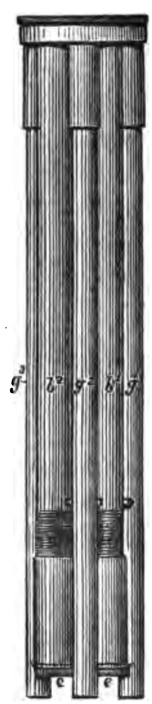
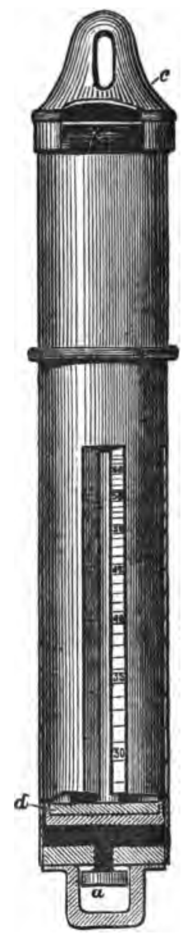



*Fig. 2*



cap with a finger or thumb applied to it where the twine is round it.

If the wire is never left a minute out of lime water except when in actual use, and if the instructions which are printed and given with each machine be faithfully fulfilled, the wire will be as fresh and bright after years of use as it is when freshly supplied with the machine.

I have drawn your attention more fully to the small form of sounding machine than I would otherwise have done had I only had the large one to show you, but they are all out at sea at present. However, it will help you greatly to understand the other; and here you see a drawing of it on the wall (see Fig. 7). Now, although Sir William Thomson invented his large sounding machine first, about eight or nine years ago, and tried it for the first time in connection with cable-laying on the Brazilian coast between Pernambuco and Para, yet it has not received nearly so much attention and improvement as the smaller one. Yet, I think the diagram shows it in its most compact and easily-worked form, as adapted and used by those on board the S.S. "John Pender." It would require a plan to show you the full arrangement for winding up the wire by means of the winch or other steam-power machinery, which it is necessary to do in depths beyond 500 fathoms. This side elevation will, however, give you a general idea.

A great many attempts have been made by different engineers to devise a better form of sounding lead than Sir William Thomson first brought out, as with it you had to drop the sounding shot in deep water, although you generally managed to bring back the tube, but without a very good specimen of the bottom. I tried to do so, and succeeded to a certain extent; but the one before you, designed by Mr. Lucas (one of the chief telegraph engineers of the Telegraph Construction and Maintenance Company) is the best and most perfect yet devised. It brings up half a wine glassfull of the bottom from almost any depth, and is in reality a most serviceable tool in connection with Sir William Thomson's sounding machine (see Fig. 7). I will let it drop upon this

SIR WILLIAM THOMSONS LARGE DEEP-SEA SOUNDING MACHINE

AS FITTED TO S.S. "JOHN PENDER."

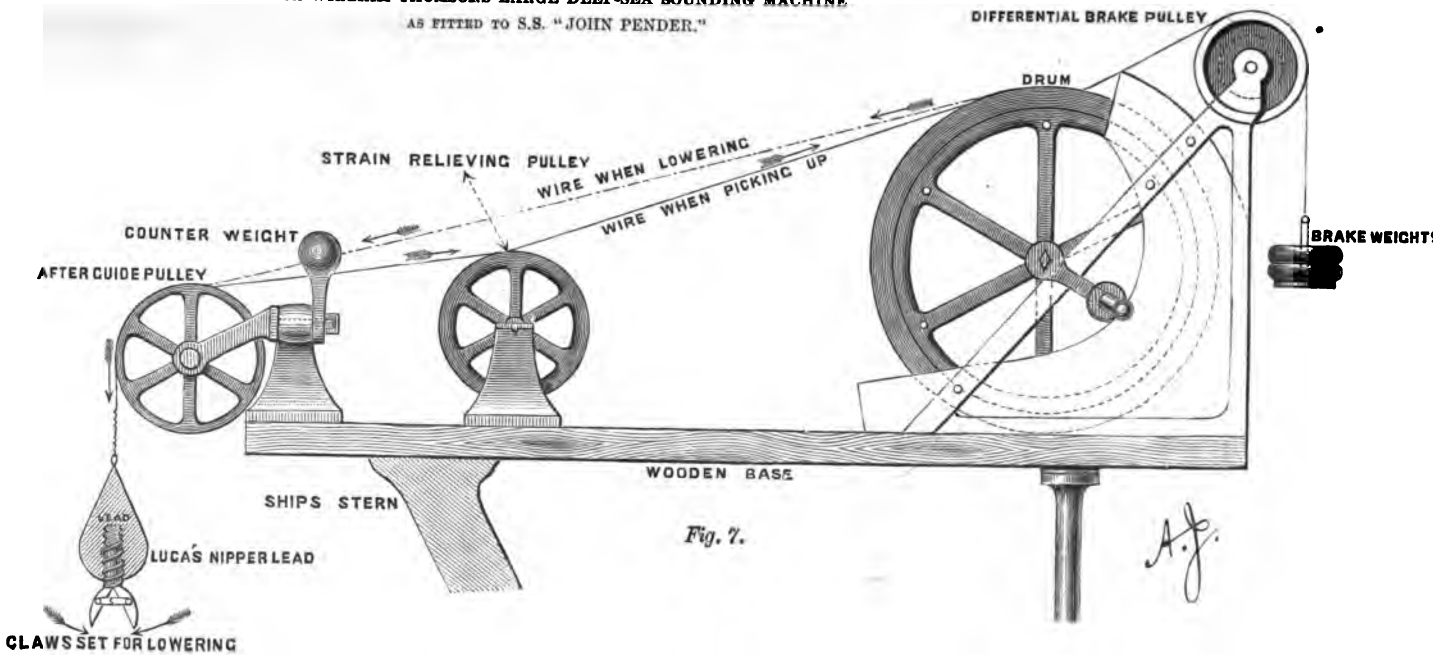



Fig. 7.

piece of paper laid flat upon the table, and you see it picks it up as nimbly and securely as if I had done it with my finger and thumb. [Experiment shown.]

Well, the telegraph ship proceeds over the proposed ground for the cable, and those in charge take a series of soundings, carefully noting the depth, nature of the bottom, position of these by latitude and longitude (or bearings and angles if within sight of land), marking every detail and circumstance, including currents, upon properly-prepared charts. The whole data are carefully weighed, and the best route chosen, avoiding a rocky and irregular bottom. A section of the sea bottom is drawn to scale in order to ascertain how much slack should be allowed at the different positions; for, as I explained a few minutes ago, if the cable does not rest upon the sea bottom at all points, a constant strain comes into play, which in time inevitably kills or breaks the cable, stopping communication till repairs can be effected.

In a report made by the eminent firm of telegraph engineers, Messrs. Clark, Forde, & Co., the following passages occur relative to the breaking of cables suspended on rocky points:—" On a rock bottom short lengths of the cable must clearly hang free over the smaller interstices of the rock, but a cable may also in certain circumstances, we consider, be left suspended for considerable lengths, even if a large percentage of slack is being paid out; for instance, the cable in question at an ordinary paying-out speed of five knots an hour will sink in a straight line, inclined at a slope not exceeding 1 in 6·3 to the horizon, so that in a depth of 1,000 fathoms the cable will touch the bottom about 6·3 knots astern of the ship.

" If anywhere the bottom has a slope exceeding this amount it is clear that the cable will be at first suspended, and then will gradually fall to the bottom if it is able to drag up slack enough.

" If the contour of the bottom is like D B C A E the cable will at some instant take the position B A F, and at the instant of touching A, B A is, of course, tight if there is any strain on the cable at the ship's stern (Fig. 8). The piece A B

will then tend to fall in the ground below it, and to do this must gather slack from A E or B D. It is possible that the cable

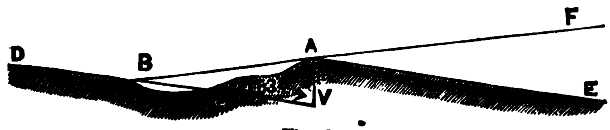



*Fig. 8.*

may on rocky ground catch on rocks both at A and B, and then it will remain suspended, possibly under great strain. The strain will depend on the length A B, and the distance along B D A E that the cable has dragged.

"Should the ground prevent a contour such as that shown below (Fig. 9), in which there is a general ascent not less than 1 in 6 for some distance, and on this slope any two summits as

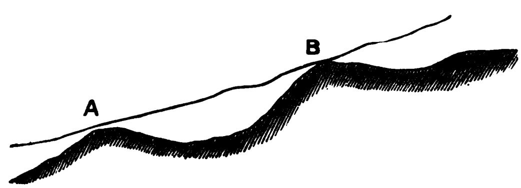



*Fig. 9.*

A and B exist, the cable will touch the points A and B at the same instant, and should it catch at both, then it will remain suspended, under very great strain, however large a percentage of slack may have been paid out.

"When the slope of the bottom is quite even it appears that

| | | | | | |
|---|---|---|---|---|---|
| 2 | per cent. | of slack | is sufficient | for an ascent of | 1 in 5 |
| 4 | ,, | ,, | ,, | ,, | 1 in 3·5 |
| 6 | ,, | ,, | ,, | ,, | 1 in 3 |
| 8 | ,, | ,, | ,, | ,, | 1 in 2·5 |
| 16 | ,, | ,, | ,, | ,, | 1 in 2·25 |
| 41 | ,, | ,, | ,, | ,, | 1 in 1 |

"The only way to partially meet this difficulty is to pay the cable out slowly, so that it may fall at a comparatively high angle, and to pay out a considerable percentage of slack."

Having obtained a careful survey, the shore end is landed by fixing or burying a strong heavy anchor in the ground in as elevated a position as possible, with a large snatch block or pulley attached, close to the intended cable house and beach, running a strong light rope on shore with boats (having first brought up the ship to a position as near the cable house as possible, and anchoring her stern on to the shore), passing the end of this rope through the shore pulley or block, and returning the loose end of the rope on board again.

This end of the rope is now firmly bent on to the end of the cable, which has been previously passed out of the ship's cable tank, and the inner end of the rope is now hauled upon by being passed several times round the picking-up drum and the machinery is set in motion. As each successive 20 or 30 fathoms of cable is hauled out of the ship towards the shore, it is bent on to small light draught buoys with a piece of spun yarn, or attached to the bows of ordinary boats, until it reaches the shore, and the end is passed into the cable hut. In this hut are two or three electricians with a cable jointer, who attach the core of the cable to their testing instruments. These electricians now communicate electrically with the electricians on board, test the cable carefully for conductivity and insulation resistance, and, if all is right, the men are ordered to fill up the trench between the cable hut and the shore, and the buoys cut adrift are picked up and brought on board. The ship now lifts her anchor, and the laying of the cable is proceeded with at once, slowly at first, until everything gets into working order; but afterwards, when type B or a depth of 50 fathoms is reached, at five to six knots an hour, even more at times.

Each individual on board (from the cabin boy to the captain on the one hand, and the men in the tank to the chief engineer and electrician) now has his special work and duty to attend to, and in a well-arranged expedition no hurry, fuss, or unusual excitement of any kind should be observable.

Some ten men in the tank, with a leading hand, carefully watch and assist the cable in freeing itself, as each coil whizzes out, and it does whizz at what would be considered a

dangerous rate by any one not accustomed to the operation. It is a most dangerous thing not only to the men engaged in the tank, but to others along the line of cable, should a "foul flake" occur—*i.e.*, one coil catch another, and lift it in a bight, for the cable, being strong and capable of bearing at least a strain of several tons, would carry everything before it, perhaps killing the men, breaking machinery, and getting inextricably mixed up, if not broken itself. The men in the tank are relieved every two hours if the tanks are small; good mechanics attend to oiling and clearing the machinery from dirt; and one is specially stationed at the brakes, to adjust the proper strain, according to the directions and calculations of the engineer in charge.

He watches this dynamometer or machine for indicating the strain on the cable, and as it rises or falls he turns the handle of a winch in order to ease or screw up the brakes, which are fixed on the same shaft as the paying-out drum. I have here had the dynamometer drawn to scale (see Figs. 5 and 6), and the necessary mathematical calculation for dividing or marking off the strains worked out. It is a simple problem in the parallelogram of forces, which I shall not go into this evening. The rotometer is carefully watched to know the lengths paid out, &c.

The electricians in the testing rooms, both on board the ship and on shore, keep up a constant searching inquiry (which, unfortunately, there is no time to explain this evening), so as to obtain all necessary electrical data for future use in case of faults occurring, and to detect the slightest appearance of a fault should it occur, when orders are at once given to slow or stop the ship if necessary.

On the bridge the captain, with the assistance of a special navigating officer on the engineers' staff, notes all bearings, takes numerous sights, and marks all courses and distances, while the ship's engineers keep the ship going at the speed required by the engineer in charge of the expedition.

The whole operation goes on like clockwork until the opposite shore or landing place is reached, when the same operation of landing the other shore end takes place, if it has

not been done previously. If so, the ship is brought close up to the buoyed end, and the final splice made. If all is electrically perfect, the health and prosperity of the cable is drunk, and complimentary messages flow through at lightning speed.

Final shore tests are taken by electricians at both ends to prove already-obtained figures, and to satisfy the consulting engineers, while daily tests are taken for a stated period (generally during one month's guarantee), in order to see that nothing goes wrong, or to give warning should any unfortunate circumstance occur.

Working the cable, or the transmission of telegrams, is also busily effected when the cable is not being tested, and it begins its useful life, to gladden many a heart by joyful news, or sadden others by the reverse, but above all, if possible, to enrich the bold speculators who launched the scheme of connecting previously unconnected lands.

We have now to deal with "Faults: how they occur, and how they are localised." We may enumerate the causes of "faults" as follow:—

1. Total breakage due to abrasion, suspension between submarine eminences, insufficiency of slack, volcanic eruptions, or terrestrial disturbances, or possibly large masses of rock becoming detached and falling across the cable in descent.

2. In shallow waters, from ships' anchors.

3. Faults caused by teredos, or marine animal borers.

4. Break of the conductor, with perfect or good insulation.

5. Latent faults in the cable when laid, developing after time, deterioration of core, joints, or sheathing.

6. Lightning.

When from any cause a submarine cable is broken, or becomes too faulty for the transmission of messages, a repairing ship, fitted with all the necessary appliances for grappling and lifting the cable, is despatched with the least possible delay to the position localised by the electrician.

But you would, no doubt, like to know how the position of the fault is arrived at, as this seems a mystery to all persons unacquainted with the laws of electricity.

I will try to make the matter plain to you by a few homely illustrations.

If you wanted to know the length of this lecture table, and were to call a carpenter or joiner to measure it for you, he would take out his rule, and having compared it with the table, he would inform you that it was so many feet and inches. You at once comprehend his answer, for the foot and inch are the units of measurement by which you and the carpenter and other intelligent people in this country are accustomed to compare and measure lengths.

Again, if you went to an ironmonger with this piece of lead, which is ten cubic inches, and asked him what weight it was, he would at once place it in one of the scales of his balance (see Fig. 10), insert known weights in the other scale

*Fig. 10.*

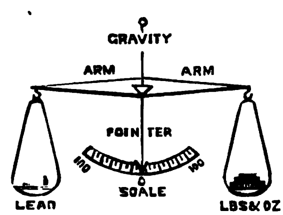
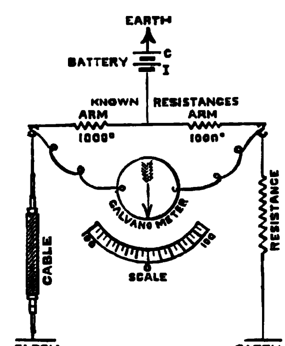



*Fig. 11.*




(as I now do here), and tell you it was so many pounds and ounces (4 lbs. or ·4 lbs. per cubic inch). You at once understand him, for the pound and ounce are in this case your units of weight. Now, if you were to become the possessor of a piece of telegraph cable, say 100 miles in length (like this piece here), and were anxious to know its electrical resistance, you would call in an electrician, and say to him—"Tell me what number of units of resistance does this piece of cable offer to the passage of an electric current?" He would attach one end of the conductor to the cable to one side of his electric balance (see Fig. 11), put the other end of

the cable "to earth," adding known resistances to the other side of the balance, and tell you that the total resistance was 1,000 ohms, or 10 ohms per mile.

The ohm is, therefore, the electrician's unit of resistance, so called from the name of the person who first found out and demonstrated the laws relating to electric resistances. The method by which the electrician set about finding out this for you was similar in many respects to that by which the ironmonger found for you the weight of the lead, only a little more scientific, and perhaps at first difficult to understand; but by aid of this diagram and apparatus I have little doubt that you will see how the result is accomplished.

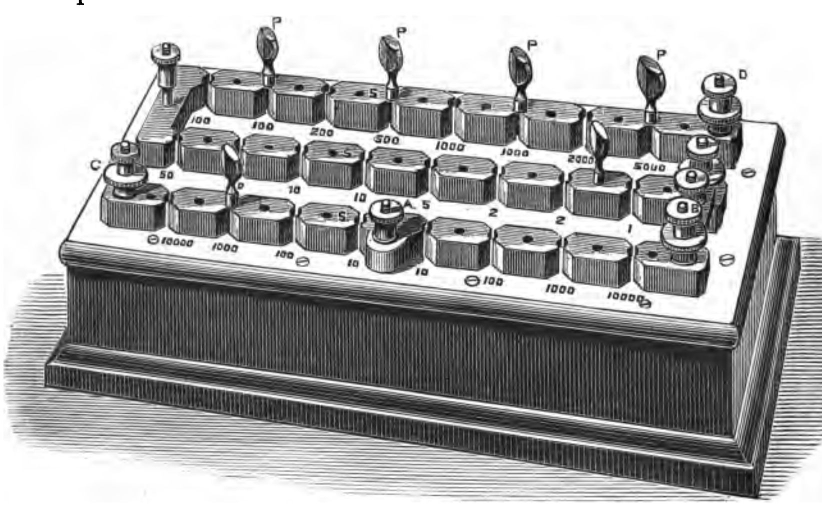



*Fig. 12.*

This pretty looking box* here constitutes the electrician's balance, called generally "Wheatstone's bridge or balance" (after the name of the great electrician, Sir Charles Wheatstone). It also contains the counterpart to the ironmonger's weights (here pointing to box and part of diagram, Fig. 11, marked resistance coils 1,000 ω).

* The one shown was lately presented, along with a galvanometer, by Mr. Matthew Gray, Silvertown Cable Works, to the Glasgow Mechanics' Institution, now the "College of Science and Arts."

These resistance coils are made up of very fine and carefully adjusted platinum-silver wires, well insulated by being covered with silk, and wound upon bobbins like ordinary thread pirns. They are arranged from 1 ohm to 10,000 ohms, so that the electrician can measure the resistance of any conductor between these amounts with even or equal arms in his bridge. This detector here is Sir William Thomson's reflecting galvanometer, and occupies the place of this pointer in the ironmonger's balance, for, like the ironmonger, the electrician when he sees this pointer steadily pointing to the middle or zero of the scale, without inclining to one side or the other, he is quite satisfied that the balance which he has got is correct.

The constant force of gravity assists the ironmonger in ascertaining the weight of the piece of lead in the same way that a constant electric force from a good battery helps the electrician to ascertain the resistance of the cable.

You see the two balances as I have drawn them upon the board. The direction of the arrows indicates the direction of gravity and of the electric current in either case.

When the electrician observes no current flowing through his galvanometer—that is to say, when he sees the spot of light perfectly steady at zero, like the ironmonger his pointer—he knows he has got a balance, and he has then only to count up, or read off the resistance in circuit from his resistance box, and that will be the resistance of the piece of cable, provided, of course, that the arms of his balance are equal.

Now, you will say, "What has this to do with finding the position of a fault in a cable?" This I will very soon show you.

Suppose your cable breaks, and you cannot send any more messages, you again call for the electrician, for you are in a worse dilemma than before. He again brings forth his inevitable balance, works in exactly the same way, but finds, say, that he only gets 300 units or ohms of resistance, and that he observes the current to flow freely to earth without fluctuation—that is, that the fault or break is well exposed.

He at once says to himself, "When the cable was good and 100 miles long, I got 1,000 $\omega$, or 10 $\omega$ per mile, and I also know it to be of uniform resistance throughout. I have only, therefore, to divide my 300 by ten, and I get thirty miles at the distance from this end. In order to make sure, however, I will take the first steamer, or the telegraph ship if possible, and go over to the other end with my never-failing balance under my arm." You say, "By all means, as quickly as possible. I am in a great hurry to know where the break is. I am losing pounds upon pounds daily, and my opponent is getting all the traffic." Over goes the electrician, attaches his balance to the other end, and reports that he gets 700 ohms or units, and dividing the 700 by ten, says it is seventy miles from that end.

I have shown you the simplest possible case that could happen. It is not always so easy, yet that is the basis or principle upon which he acts. But as different as are the extremely fine calculations and weighings of the analytical chemist to those of an ordinary grocer, so are those of the submarine electrician to those of the man who runs up an ordinary wire along the streets for working a telephone.

Having found the electric resistance to the fault from shore in ohms, and converted it into nautical miles, he has then to plot off the distance on the chart, allowing carefully for any slack that may have been paid out, for although the length of the cable may be 100 miles—as in the case assumed—the straight distance across may be only 80 miles, or 20 per cent. slack, and thus it is possible to make a much greater error in plotting off the distance on the chart than the limit of nicety to which the electric tests directed you. However, by carefully considering the data, and with some practice, the thing is generally arrived at pretty well.

During the operation of sounding, it is well to ascertain at the same time if any currents or tides exist, and the allowances to be made for these and winds during the future operation of grappling and lifting.

Soundings having been obtained, the next thing to do (if

no good landmarks are available for taking accurate bearings) is to place a "mark buoy."

Mark buoys should be large, ride well, and with an easily-distinguishable beacon fixed to the top of as tall a pole as the buoy will conveniently carry. "Bird cage" beacons are, as a rule, preferable to flags, from the frequent occurrence of the latter becoming entangled and wound round the staff, or not standing out well when the wind is light. Spherical silvered globes have been prepared, and no doubt would be easily distinguishable at great distances when the sun was bright, owing to the reflected rays of light, but they have not been practically adopted. At night, flags, beacons, or globes are of no avail, and we still lack a good plan of distinguishing mark buoys from sunset to sunrise. Lamps are used, but they necessitate the lowering and sending away of a boat's crew to fix them, which under the circumstances of heavy weather is impossible, and is always shunned if it can be avoided; besides, they are liable to become broken, upset, or extinguished. Buoys filled with gas upon Pintsch's plan, seen at the recent Gas Apparatus Exhibition in this city, are perfectly satisfactory, and should be supplied to every telegraph steamer.

A good electric light, such as that now used in the navy and elsewhere, would assist in discovering a buoy at night; but I doubt whether it would be sufficiently handy to enable the ship to be kept up to within sight of a mark buoy on a rough, windy night. It has proved very serviceable in landing shore ends and lighting up paying-out gear, &c.

Now, having ascertained the depth of water, nature of the bottom (if possible), currents, winds, &c., and fixed the position of our mark buoy by careful observations, we are ready to commence grappling. But before describing the operation, it may be as well to give a general idea of the grapnel system, as at present used, with the appliances for working the same. Referring back to Fig. 4, we have—(1) Tank or platform for holding or supporting the grapnel rope; (2) picking-up gear; (3) dynamometer; (4) fair-lead pulley; (5) bow baulks and sheaves; (6) grapnel rope; (7) grappling

chain; and (8) grapnel. The grapnel is attached to about 15 fathoms of $\frac{3}{4}$-inch or $\frac{7}{8}$-inch grapnel chain. The chain in turn is shackled to the grapnel rope, which passes over the bow and fair-lead pulleys, underneath the dynamometer pulley, and with three or, if necessary, four turns round the picking-up drum, ending in a coil, placed in a suitably-arranged tank or platform behind the picking-up gear. The drum is revolved by a steam-engine and gearing, either directly or indirectly attached to its framing. It can also be stopped or eased by friction brakes, suitably fixed to the pulleys on one or other of the motion shafts. The dynamometer (see Figs. 5 and 6) is generally placed midway between the picking-up drum and the fair-lead pulley, and indicates by a pointer and scale the strain brought to bear upon the grapnel rope—*e.g.*, when the grapnel is being drawn over the ground, or when elevating the cable. The fair-lead pulley is simply a loose pulley, free to run upon a shaft and bearings, as well as to move longitudinally along the same, and consequently guide the grapnel rope from the bow to the dynamometer pulley, or *vice versa*. The bow sheave is the last guide which the grapnel rope receives on passing from or to the ship. The grapnel rope is composed of steel wires, each wire being served with hemp, varying in size and strength according to the nature of the ground and depth of water. The grappling chain, which is attached between the end of the grappling rope and the grapnel shank, is generally 15 to 20 fathoms long, and composed of ordinary $\frac{3}{4}$-inch or $\frac{7}{8}$-inch chain, and serves to protect the grapnel rope from becoming worn on the ground, as well as to keep the grapnel more or less well buried, and up to its work when in action. The grapnel itself is of various forms and sizes, according to the nature of the ground to be worked upon. For instance, there are long-toed, short-toed, self-relieving-toed, centipede, chain, and other grapnels; but for the present let us select the common centipede grapnel, with a trail chain behind to act as a damper or preventive against jumping, and commence lowering it to the bottom of the sea preparatory to the grappling. The grapnel rope is lowered by the picking-up gear, and as a

rotometer or length measurer is always attached, you can easily ascertain when the grapnel should be nearing the bottom. The ship should, therefore, be moved easy ahead, in order to prevent the chain and grapnel becoming jumbled in a heap, and care should be taken not to pay-out much rope in excess of the depth. When the grapnel and chain have reached the bottom, and a sufficient quantity of rope has been paid out to insure easy working without trailing the rope on the ground, the grapnel rope should be carefully parcelled or served with matting where it is likely to become chafed on the bow sheave, or fore-foot and side of the ship —a circumstance which is very likely to occur if there is any swell, or up-and-down motion of the ship.

The operation of grappling is now fairly commenced, and we have taken precautions that all necessary stoppers and appliances are at hand, in the case of hooking cable, or the grapnel rope taking a run, under a sudden strain due to catching rocks. The ship should, as far as possible, be brought head to wind and tide—that is, working against any local forces, so that she may be the more easily checked in her forward movement, should anything occur to require this being done; or she may be allowed to drift stern first, only moving the engines when it is required to keep her up to the course intended.

The responsible telegraph engineer or officer in charge now sits or stands upon the grapnel rope, watching the strain by dynamometer, but mainly trusting to the indications felt by the nerves of his hands, feet, or posterior. He can easily distinguish in shallow waters between the gradually—I might say, softly—increasing strain, denoting "cable hooked," and the sudden, sharp, wicked strain, intimating "rocks engaged." But in deep water, or when working on stiff clay bottom, it requires great experience and judgment to tell correctly whether the cable has been hooked or the grapnel is simply labouring through heavy ground. This difficulty is, of course, increased with the depth, as the vibrations and strains imparted to the rope are lessened, and the indications consequently deadened.

Rocks are a great source of trouble, and have caused no end of breakages to grapnels, ropes, &c., besides great waste of time. It is no uncommon occurrence for a repairing ship to have three or four grapnels rendered useless in a morning's work.

In the meantime, let us suppose that we have been lucky in hooking the cable, and that we have commenced picking-up. This is an operation which requires considerable experience, as the ship has to be carefully and expertly handled, so as not to bring any undue strain on the cable, as well as always to keep the grapnel rope vertical, or as nearly so as possible, in order to prevent the grapnel skidding or sliding along the cable. The speed of picking-up should be so regulated that surging and jerking may be avoided. Many a cable has been

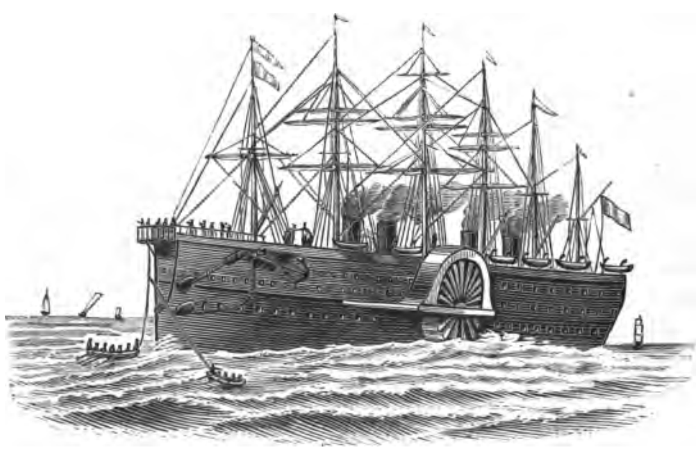


*Fig. 13.*

broken during picking-up by an over anxiety to bring it smartly to the surface, and not giving time for the ship to come to, or easing out rope when she fell off. Of course, the ease with which a cable may be picked up greatly depends upon the amount of *slack* originally laid. For cables laid in waters up to 1,000 fms., it is most decidedly advisable so to arrange the slack according to the depth, that the cable may be picked up on the bight when the time comes for it to be

repaired; and a safe rule would be to lay cables with 1 per cent. of slack for every 100 fms. of depth. When a cable has to be repaired in waters over 1,000 fms., it is only under exceptionally favourable circumstances that we can expect to bring it up on the bight without breaking. In such great depths, the cable has first to be hooked, lifted a certain height and buoyed, then elevated or eased by a ship some 3½ miles from the buoy, while another ship catches and brings the cable to the surface, between the buoy and ship. To obviate all this trouble or difficulty, grapnels have been devised for cutting one side and bringing up the other. Fig. 13 shows the "Great Eastern" with cable at bows. You can see a large drawing of this down stairs, exhibited by Sir James Anderson, her late captain.

Assuming that the cable has been successfully elevated to the bows, it should be securely stoppered on each side of the grapnel nip to lengths of strong coir or grapnel rope, the one leading over the starboard and the other over the port-bow sheave. With three bow sheaves this can easily be done, the central one being occupied by the grapnel rope, and those on either side for heaving-in or slacking-off one or other of the ends of the cable.

There are two plans at present in use for stoppering a cable at the bows, both of which necessitate the lowering of a man over the side (see Fig. 14). The one is that of simply nipping the cable on the bight of a chain and link; and the other, certainly the more secure, although it may take longer time, is that of taking a rolling hitch and half-hitch with spun yarn seizings before and behind as well as through the last link of the chain stopper.

I think it might be quite possible to devise some means of clamp arrangement, whereby the loss of time and danger arising from stoppering the cable at the bows might be avoided, as well as a plan of severing the cable when stoppered, without having to let a man over the side in a boatswain's chair to effect the same with file and saw.

The cable having been securely stoppered on each side of the grapnel nip it should be cut, and heaving-in commenced

by the picking-up drum on the one side while slacking out on the other.

This plan is preferable to that of buoying one end, as it permits of having both sides tested electrically and a knowledge of the condition of the cable ascertained before picking up towards the fault, without materially altering the ship's position.

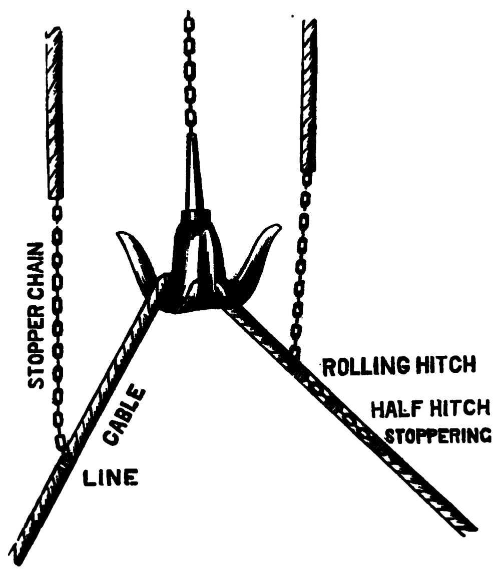



*Fig. 14.*

If the good side be first brought on board it can, of course, be sealed, let go, and buoyed before testing the other, unless (as is sometimes advantageous) "shore" should be informed how much may be expected to pick up, &c.

Suppose that the good side has been buoyed—that is, its end securely fastened to a length of chain with mushroom anchor, and sufficient buoy rope, with riding and bridle chains, &c., between the same and the buoy,—it is always best to let the cable down to the bottom when buoying an end (not so in the case of a bight), and, therefore, to depend entirely upon

the mushroom, buoy-rope, and chain for holding the buoy from drifting, insuring at the same time that the cable, when once done, bears no part of the strain.

Everything being clear, it is now time to pick up towards the fault. This is done by steaming the ship gently forward over the line of the cable, elevating and taking it in at the lowest possible strain by the picking-up gear, and coiling the same in one or other of the cable tanks. Sometimes the cable as it leaves the ground gets jammed in a rock, and great care has to be taken in extricating it without overstraining or breaking.

It is always a special point of interest to those engaged in repairing a cable, and more especially to the electrician, to see and examine the fault. Care should be taken when the fault or broken end comes on board to avoid jamming or altering its form or condition in any way before it has been thoroughly examined and tested, *as every fault picked up has a history of its own, and tells a tale furnishing valuable experience.*

All information regarding the fault should be collected, sifted, and arranged, in order to assist in dealing with, and localising more correctly, similar ones in future, and guarding against recurrence.

Of course, if a broken end comes on board, or the cable gets broken in picking up, the operation of grappling, hooking, and lifting the cable has to be repeated as just described, in order to secure the other end, and find that it tests all right.

Having secured it, if it tests all right, a joint and splice have to be made to the good cable on board which it is intended to lay in.

Jointing and splicing on board ship when out on a "repair" mission have to be effected with the greatest possible expedition in order not to keep the ship hanging on to the cable longer than is absolutely necessary, and requires to be done by men specially trained for the purpose.

The process of jointing the conductor and gutta-percha core of a cable at sea is a very interesting one, but, unfortunately, we have not time to consider it to-night. Preparatory

to jointing, however, the sheathing and yarn servings have to be prepared and arranged according to the form of splice to be made. If the types of cable are of the same size and lay, a "factory splice" may be made, that is, the wires are inlaid; if of different types or lay, an "overlapping splice" will be best and quickest. In either case the iron wires on one side of where the joint is to be made have to be unstranded in

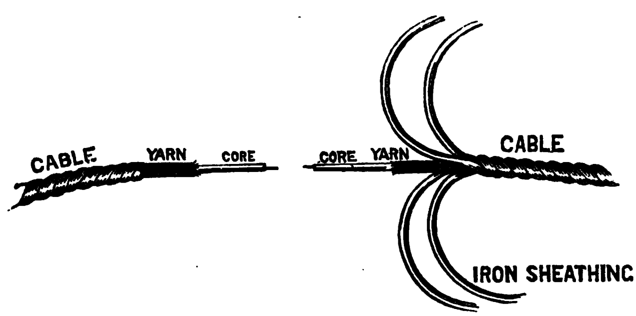



*Fig. 15.*

twos or threes to a distance, say of seven or eight fathoms, bound there with spun yarn, and the core cut off within three or four feet of the fastening, while those on the other side are also firmly bound with spun yarn, but cut off square, leaving about two feet of core sticking out.

The yarn serving is neatly laid back and fixed to the iron sheathing on both sides—the two projecting ends of the core being sufficient for the jointer to work upon without impeding him by the iron sheathing.

After the joint has been finished, cooled, and tested, the yarn servings are drawn forward and neatly bound over the joint to protect it from the sheathing.

The iron wires, which were unstranded and laid back, are now brought forward, and either alternately inserted in the place of those on the other side, being cut off at distances of five to six feet apart, making (what we have just mentioned) a "factory splice," or drawn over and laid round the sheathing on the opposite side. The sheathing is secured or bound here

and there with fine soft iron wire, and the splice, whichever way it may have been done, is tightly served with spun yarn, and is just as strong as any other part of the cable of the same type when well done.

Paying out the new cable is now commenced, and continued until the buoy attached to the other end is reached, when the buoy with its moorings, &c., and the cable attached is lifted and brought on board. Both sides are now carefully tested, and if all right, a joint and splice are made between the two ends, and the bight carefully let go over the ship's side, tightening it as far as required before slipping.

There are almost as many precautions and observances to be attended to in paying out a few miles as a few hundred. But in paying out a short length (anything up to ten miles) it is best to pay it over the bows, as it saves the necessity for passing the cable from stem to stern, or *vice versa,* when the first end buoyed has been reached. In fact, I am of opinion that it would be well if all repairing ships were fitted with break power on the same shaft as the picking-up drum, suitably arranged for paying out—in which case there would be no necessity whatever for paying out machinery aft, the result being a saving of first cost and room, besides dispensing with a lot of top weight, and confining the cable work to the forward part of the ship.

In conclusion, we shall now give you an idea of the different kinds of grapnels that have been and are still used for hooking and bringing to the surface submarine cables.

The first kind used, and often used still, is that known as the long-shanked five-pronged grapnel. The prongs and shank are all rigidly welded together, the shank being about $4\frac{1}{2}$ ft. long, with a swivel end.

Another and now more commonly used form is that known as the "centipede grapnel." It consists of a square bar of iron with a ring fixed at each end, and a series of double prongs wedged into holes in the shank. This form of grapnel has two or three advantages over the five-pronged one. The prongs can be removed and others refixed on board ship without the difficulties of welding; it is easier to make; it affords

a double chance of catching the cable (that is to say, should the front toes miss, those behind may still catch the cable); and it can be furnished with a trail chain or weight attached to the after ring bolt to prevent jumping.

Both these forms of grapnel, however, labour under the disadvantage that, if once engaged with rocks or other fixed obstacles, the greatest difficulty is experienced in relieving them without breaking the toes or some part of the grapnel system, either rendering the grapnel useless for further work, and necessitating its being elevated on board ship, and a fresh one attached, lowering the same, and commencing the work over again; or, in the case of the grapnel rope giving way, losing part of the rope, chain, and grapnel.

While repairing the Para-Pernambuco section in December, 1875, we experienced an immense deal of trouble from this cause, owing to the very hard rocky bottom there; and it occurred to me then that a grapnel might be constructed with self-relieving toes, so as to give way when engaged with rocks, but so constructed that the toes should automatically assume their normal working position immediately after slipping over the rocks. I mentioned my idea to Mr. Wm. F. King, Engineer-in-Chief to the Western and Brazilian Telegraph Company, and we designed a form of grapnel to effect this object. On returning to England, I carried out several improvements, with the assistance of Mr. Alexander Glegg, the maker.

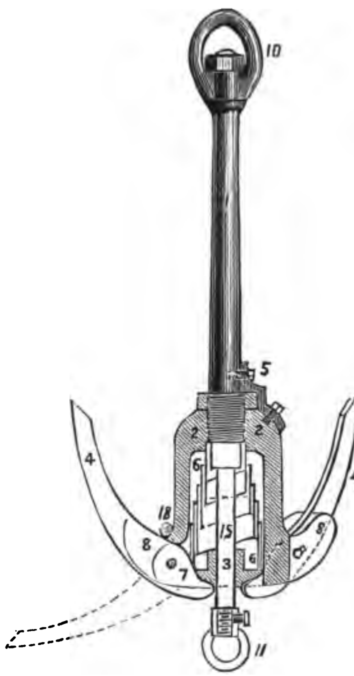
Here is a full-sized working grapnel before you, sent here by Sir James Anderson for exhibition, along with some other interesting things which I have shown you, and here is the model. I will now show it in action upon these miniature rocks, placed on the table to represent the sea bottom.

This grapnel permits of working on rocky or even ground without fear of sticking, at the same time affording every facility for catching the cable and retaining the same when caught, as well as preventing the sharp nip caused by ordinary grapnels, by having broad, well-rounded shoulders, upon which the cable may rest when being elevated to the surface.

The large drawing before you, of which Fig. 16 is a

copy, represents a sectional elevation of my improved grapnel. There is the shank of the grapnel, 1, with the cylindrical boss, 2, which may be made of cast steel, malleable iron, bronze, cast iron, or other suitable material, and which contains and protects the spring, 6. This spring may be constructed on the volute, spiral, or any other principle, and may be made of steel, or india-rubber, or both combined—a volute spring being preferred. Round the lower end of the boss project short toes or prongs, 8, which are cast or otherwise formed solid with the boss, each pair of toes embracing a much longer toe, 4, by preference composed of wrought-iron or steel, which is held in position by a fulcrum pin, 7, round which it is capable of revolving. The shank, which has attached to its upper end a shackle, 10, provided with a swivel joint, is firmly screwed to the boss by a long coarse pitched thread, secured by a jam nut and clamp plate, 5, in any desired position. The diameter of the shank is then reduced, as shown at 15, and the reduced portion passes down through the boss, and terminates in a screwed end, to which is attached the shackle or eye, 11, for the "trail" chain. There is a movable piston, 3, capable of sliding up the reduced portion of the shank, 15.

*Fig. 16.*




JAMIESON'S GRAPNEL.

The apparatus operates in the following manner:—The toes, 4, when engaged by rocks or other obstacles, are pressed outwards, and rotate round their respective fulcra, 7, their inner ends bearing and pressing against the movable piston,

3, which travels up the reduced portion of the shank (within the boss), compressing the spring, 6. This movement may continue until the toes move round to the angle shown by dotted lines on the left hand side of the figure, which position is amply sufficient to relieve the toes from any rock or other obstacle. As soon as the toes are released, the piston is forced down under the action of the spring, and in its turn acts upon the toes, thereby restoring them to their working angle. On the other hand, should the cable be caught, it slides down the toes, 4, into the fillet of the shorter toes, 8, where it remains, as seen in section at 18. Any amount of strain brought upon the cable in bringing it to the surface has no effect upon the spring, 6, or long toes, 4.

This grapnel has already proved of good service in repairing cables in South America, under the skilful management of Mr. King, and has been adopted by the Eastern Telegraph Company, and other companies are also making inquiries about it.

The saving in time alone effected by not having to elevate the grapnel to the surface for inspection or renewal will be found to more than repay its extra cost in a single expedition. The grapnel can be taken to pieces and put together again in twenty minutes.

Such are a few of the chief points connected with the laying and repairing of submarine telegraph cables. I hope what I have said has been made sufficiently clear by the assistance of these large drawings and models; so that, should you read in the daily papers of a cable expedition being started to connect this and that outlandish place, or should you hear of one of the Atlantic cables being "down," you will now have a more exact idea of the engineering difficulties that arise, and how they are overcome.

Finally, I must say that I cannot understand how it is that so very few of the "cable fleet" (numbering nearly twenty-five fine steamers) have been built and equipped on the Clyde; or that no cable-laying machinery should ever have emanated from north of the Tweed. The engineers and shipbuilders of Glasgow might well take an example from their talented

townsman, Sir William Thomson, who has not only invented but designed and had made here, by Mr. White, of Sauchiehall Street, the most perfect submarine telegraph instruments, without which long cables would never have paid; and they should come forward and show the world that they could not only build the best cable ships, design and make the best machinery, but construct the cable itself better and cheaper than it can be done elsewhere.

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I am indebted to Sir James Anderson for the map of the "Eastern and South African Telegraph Company's System;" to *The Electrician* for Figs. 1, 2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, and 15; to Sir William Thomson, for the diagrams 1, 2, and 3 of his small Sounding Machine; to *Engineering* for Fig. 4 (telegraph ship); to *The Telegraphic Journal* for Fig. 16 (my grapnel); and to Naval and Marine Engineering Exhibition for Fig. 7 (Sir William Thomson's large Sounding Machine).

# ON SOME FUNDAMENTAL PRINCIPLES IN NAVAL ARCHITECTURE AND MARINE ENGINEERING.

By ROBERT MANSEL, Esq., of Messrs. Aitken & Mansel.

*ON FRIDAY, 4th FEBRUARY, 1881.*

The subjects to which your attention is to be directed this evening are stated to be Fundamental Principles in Naval Architecture and Marine Engineering. It is proposed, in the first instance, to consider a subject common to the science of both arts; and, in reality, the most important and fundamental of all their principles.

Outlined and conditioned by Sadi-Carnot in 1824, and in its experimental and scientific statement completed by Dr. Joule and Sir William Thomson about the close of 1848, it forms a definite answer to the important problem: in a mechanical point of view, what is the precise relation between a given definite amount of heat expended, and the *power*, or *capability of performing work*, which it is possible to obtain from that heat?

Carnot's views on this matter were embodied in a small pamphlet, entitled "Reflections on the Motive Power of Fire, and on Machines proper to develop that Power," which attracted little notice when published (indeed, it is stated, a part, with further deductions and applications, has only been published recently), and, owing to the subsequent death of the author, had very nigh passed into oblivion. In 1834, M. Clapeyron, a mining engineer, who had recognised the rare merit of this pamphlet, published a mathematical commentary upon it, which also contained its substance. In 1837, this paper of Clapeyron's was translated and publishea

in Vol. I. of "Taylor's Scientific Memoirs." Finally, at the end of 1848, "An Account of Carnot's Theory," with deductions and applications, formed the subject of a communication to the Royal Society of Edinburgh, and is to be found published in the Transactions of that body—the author, the present distinguished Professor Sir William Thomson, by this paper, and his other labours in this field, having laid the foundations and most valuable parts of the superstructure of the Dynamical Theory of Heat in its mathematical aspect.

Professor Tait, with great propriety and truth, has written —"Carnot's claims to recognition are of an exceedingly high order, not merely upon his method, which is one of startling novelty and originality, but upon the fundamental principle upon which he based his mode of comparing the heat employed with the work produced from it. . . . Every reasoner (who has applied himself to the subject of heat since Carnot) has gone right, so far as he has attended to Carnot's principle, but has inevitably gone wrong when he forgot or did not attend to it."

With all this I most heartily concur, but, as with all things human, some flaw or imperfection exists, or can be imagined; and Carnot's deductions, which were arrived at by simple but conclusive reasoning, without the use of mathematical processes and symbols, form no exception to a general rule. There is no necessity to hide the fact, that at least two eminent men, the late Dr. Rankine and Professor Clausius, nigh simultaneously, in 1850, professed to discover a most grievous fallacy in Carnot's conception of heat; and though it did not influence any result in the slightest, they considered they were under the necessity of substituting principles proposed, respectively, by themselves, which were alleged to be free of imperfection. The error referred to was a misstatement, so evidently inconsistent with Carnot's whole reasoning, that a year or two previous to this, a verbal correction by Dr. James Thomson put the matter right. Even as it stood, it was incapable of misleading any thoughtful man, but, like the proverbial chip in the porridge, though doing little harm or good, was better absent.

In a concise form, numbered for reference, as given by Clapeyron, who has stated the basis of Carnot's researches to be the fertile and incontestible one, "the absurdity which arises from admitting the possibility of producing absolutely either the power or the heat," Carnot's chain of reasoning led to the following deductions :—

1st. When heat is employed to develop power, there is always the passage of a determinate quantity of heat from a body at a higher to a body at a lower temperature.

2nd. There is a loss of power whenever a direct communication of heat takes place between bodies of different temperatures; and the maximum of effect cannot be obtained but by means of a machine in which only bodies of equal temperatures are brought into contact.

3rd. Our knowledge of gases and vapours enables us to reason as if such a machine was strictly practicable, and the power developed under these conditions is the greatest that is possible to realise, and is the same whatever the gas or liquid employed, being quite independent of its chemical nature, quantity, or pressure.

4th. A definite amount of power, and a quantity of heat, passing from a hot to a colder body, are quantities of the same nature, and may be substituted one for the other reciprocally, in the same manner as in mechanics, a body falling from a certain height, and a mass moving with certain velocity, are quantities of the same order, and can be transformed one into the other.

5th. If by passing heat from one body to another in some other way it was possible to realise a larger quantity of power, we should employ one part of this power to restore heat to the first body, and have a residue created absolutely without consumption of heat; an absurd result which

would imply the possibility of creating either power or heat in a gratuitous and indefinite manner.

6th. The machine implied in the foregoing statements is strictly reversible—that is to say, from a given quantity of heat operated on we may obtain a definite amount of power; or, reversing the action and expending a given amount of power, an equivalent quantity of heat will be developed.

There are other deductions principally referring to gases, and falling beyond the scope of the present paper; and I now ask you to refer to the first paragraph, in order to put its statement into less general terms. To the question: What power, E, is developed and given out when a given quantity, Q, of heat passes from a body at the temperature $t_1$, into another at a lower temperature $t_2$—subject also to the condition of the second paragraph, that in this action, bodies at unequal temperatures are not brought into contact?—stated, in the form of an equation, Carnot's answer, as given in our first paragraph, or, in a converse form involved in the fourth, was,

$$(1) \qquad E = CQ\,(t_1 - t_2).$$

In words, the power E is equal to the continued product of a quantity, C, into the quantity, Q, of heat, into the difference of temperatures. To fix ideas, it is assumed that the unit of E is a foot-pound; and that of Q the quantity of heat that would raise the temperature of a standard pound of water by one degree on the Fahrenheit scale, in which the temperatures $t_1$ and $t_2$ are also stated.

The quantity C, however, is still undefined; it has been named Carnot's function, although Carnot did not live to determine its true meaning; but, from such experimental data as he could command, he deduced that it was not a constant co-efficient, but one diminishing slowly with rise of the higher temperature. Clapeyron arrived at a like result

with a greater variety of data, and between 1847 and 1848, the very extensive and valuable researches on steam conducted by Regnault for the French Government, enabled Sir William Thomson to calculate its numerical value through a range of temperatures from 0° to 230° on the Centigrade scale.

Dr. Joule, for some time previous to this, had been conducting a series of most valuable researches on a kindred but different problem, briefly sketched as follows:—When power is expended doing work on the friction of a solid—for example, in boring a cannon, an experiment which long before had been keenly investigated by Count Rumford; in the friction of two pieces of ice, experimented on by Sir H. Davy; in the friction of a fluid—or, when power is expended in compressing a practically perfect gas; in each case the effect is the same as if we had communicated heat to the body experimented on; and the relation between the heating effect thus obtained and the power expended in producing it, which we may name the heat equivalent of the power; by some of the foregoing and many special lines of inquiry, was determined by Dr. Joule to have the definite value, Heat Equivalent $= \dfrac{\text{Power Expended}}{772}$.

or, the power expended, in foot-pounds, E, divided by 772, is the number of units of heat, Q, developed. Denote the coefficient 772 by the symbol J, and we have,

$$Q = \frac{E}{J}. \tag{2}$$

Dr. Joule being in friendly communication with Sir William Thomson, and knowing him to be engaged in the investigation of the quantity C (Carnot's function), Sir William Thomson has placed on record, that in a letter to him from Dr. Joule, dated 9th December, 1848, the important suggestion was made, that the general value of this quantity is given by the simple relation,

$$C = \frac{J}{t + 461};$$

that is to say, directly as the value of the co-efficient, J, and inversely as the absolute temperature: a view which has been confirmed by experience; and Dr. Joule is thus entitled to the honour of having his name associated with that of Carnot in the definite solution of the more important problem—namely, the *true practical* value of the mechanical equivalent of heat, in contradistinction to that which is usually but questionably termed the mechanical equivalent of heat, instead of that which this term oftener represents, the *heat equivalent* of expended power. Dr. Joule, with the modesty and absence of self-seeking which is usually found in a man of true genius, has sought to assign the credit of this to Sir William Thomson rather than himself, a difficulty which would not have arisen with several writers on thermodynamics who might be named; and it seems to me, that Dr. Joule, Sir William Thomson, and his brother, Dr. James Thomson, have all been most honourably associated in the completion of Carnot's problem, and are entitled to an amount of credit which must be denied to other writers, who, in trying to be original, with little discrimination have attempted to discredit Carnot, and, in so doing, have only shown themselves to be ungenerous and unjust. Recurring to the value of E on a preceding page, and in it writing for C the value found above, you will see that we obtain,

$$(3) \qquad E = JQ\,\frac{t_1 - t_2}{t_1 + 461}.$$

This expresses the maximum power which it is possible to obtain from a given quantity, Q, units of heat; and, as will be seen at a glance, depends as much upon the fall of temperature as the quantity of heat.

Again, let us add the number 461 to each of the terms $t_1$ and $t_2$ of the numerator; obviously, since the one is positive and the other negative, this will not alter the value of the numerator, but assists in reasoning out the following theorem:—

If from $(t_1 + 461)$ a definite quantity of any kind, $(t_2 + 461)$ a smaller quantity of the same kind be subtracted, their

difference, divided by the greater, can be nothing but a mere numerical ratio, whose value must be less than unity; which ratio being denoted by f we have,

$$E = JQ \frac{(t_1 + 461) - (t_2 + 461)}{t_1 + 461},$$

$$E = JQf. \tag{4}$$

In which f is the ratio of the difference of temperature to the absolute temperature; the higher being the temperature at which the working body stands at the beginning of the process, and the lower, the temperature to which it sinks by doing work *alone*, irrespective of any loss from other causes. By absolute temperature is meant the temperature by Fahrenheit scale, with 461° added; the precise meaning of this latter number is this: By induction from experience, within attainable limits of temperature, it would seem that absolute zero, or the point at which matter would contain no heat, for practical purposes, may be taken about 461° below the point at which, from the state of knowledge at the time, Fahrenheit supposed heat to commence, and hence marked zero on his scale. Temperatures measured in this way, from the assumed *true zero*, are 461° higher than the ordinary scale figures, and are then called *absolute temperatures*.

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Engineering, like Naval Architecture, though in a less marked degree, as a practical constructive art has been in advance of the science of that art; and, necessarily so, if we adopt Sir John Herschell's definition of science as "the knowledge of many orderly and methodically digested and arranged so as to become attainable by one." Thus it is, when we have had the true principles and important facts of the art eliminated and arranged, it is most instructive and valuable to look back upon the practice of the founders of the art, in order to recognise that these principles, possibly in a rude unrecognised form, lay at the bottom of the wise action of those who may have long since passed away.

For example, look back to the time when James Watt had approximately determined the density of steam, next proceeded to take steps to diminish the large excess of steam which he found necessary to supply to the cylinder beyond the actual volume swept out by its piston. His published letters and official documents show how just an estimate he formed of one phase of the principle embodied in the second statement in Carnot's conclusions: "The maximum of effect cannot be obtained but by means of a machine in which only bodies of equal temperatures are brought into contact." Thus, letter to Dr. Roebuck, 11th February, 1769: "I wrote you last night of my having taken the engine asunder to add an external cylinder and a thinner bottom; for at first when the cylinder is cold, there is a small quantity of water left in the cylinder. Immediately on producing the vacuum this water is *converted into steam* and *thereby cools the cylinder considerably.* Now if there is an external cylinder, and the bottom of the *internal one is thin*, the steam on the outside will warm it again instantly, and no steam will be condensed next time." And, in his first specification we have the declaration: "My method of lessening the consumption of fuel consists of the following principles: First, that the cylinder must, during the whole time that the engine is at work, be kept as hot as the steam that enters it—first, by enclosing it in a case, &c. . . . secondly, by surrounding it with steam or *other heated bodies.*"

The remainder of the principle, with more justice, will be found embodied in the practice of some of his contemporaries. Thus higher pressures of steam and higher rates of expansion than usual in Watt's practice were carried out by Trevethick and others. Expanded steam, instead of steam at atmospheric pressure, is said to have been employed in Newcomen's engine, by Smeaton, before Watt's time; and, at the commencement of this century, in the county of Cornwall, Arthur Woolfe had carried out a further improvement, and, by the addition of a second cylinder in which the steam was further expanded after passing out of the first, is said to have accomplished a saving of one-fourth of the fuel taken by the best type of the

contemporary condensing engine. It is stated Woolfe proposed his improvement when he laboured under a curious misconception as to the law of expansion of steam—supposing that steam, say of four or five pounds pressure above the atmosphere, would expand to four or five times its volume, and then be found of atmospheric pressure! Experience would soon correct this fallacy; and, in his practice, Woolfe allowed one volume additional for every ten or twelve pounds by which the steam pressure exceeded the atmospheric. It is also stated experience led him to believe there was little or no sensible additional economy when expansion was carried above eight or nine times. Some may think there is detraction in this; but, considering the circumstances under which Woolfe's labours were carried out, and viewed in the light of true theory, it is rather an instance of the far-seeing sagacity which has honourably and indissolubly connected Woolfe's name with the form of steam-engine commonly called the "compound engine."

Woolfe's high-pressure steam, expanded down in two or more cylinders, is the practical way in which we attain a large fall of temperature with the least contact of bodies at unequal temperatures. In each cylinder the temperature falls by doing work, and is then discharged into the condenser at the nearest practicable approximation to its temperature; for it must be borne in mind that it is the fall of temperature or intensity in doing work, not, as often erroneously stated, the temperature of the condenser, that constitutes the $t_2$ of the formula. In practice we only approximate to the conditions laid down for the maximum of efficiency—these give the limit to which we strive to attain, with the perfect certainty that they can never be surpassed.

In illustration, let us take steam at 69·2 lbs. actual pressure, and 302° temperature (deducting 14·7 for atmospheric pressure, the apparent pressure will be 54·5 lbs.), and, by doing work, let the temperature sink to 104°, then $f = (302° - 104) \div 302° + 461) = ·260$ the fraction of the real power in the steam obtained; and, taking another case or two, as follows:—

| | Apparent Steam Pressures. | Corresponding Temperature $t_1$. | Value of f when $t_2 = 104$. |
|---|---|---|---|
| I., . . . . | 54·5 | 302 | ·260 |
| II., . . . . | 100·4 | 338 | ·293 |
| III., . . . . | 148·6 | 365 | ·316 |

It will be seen that increase of pressure much exceeds the ratio of increase of efficiency, supposing we were able to fulfill the conditions to obtain theoretical perfect action, but which are more difficult to approximate to, the higher the pressure we employ.

About a year ago I had the honour to preside at a meeting of the Institution of Engineers and Shipbuilders, at which was read a paper by Mr. Frederick J. Rowan, giving a description of methods by which, for many years, his father, the late Mr. J. M. Rowan, had striven to improve marine engineering practice by the employment of comparatively high pressures of steam, surface condensation, and compound engines.

Mr. Rowan modestly placed these facts upon record, with the admission that in most cases they did not meet with the success reasonably anticipated; and, though often seemingly obtained, in the sequel unforeseen practical difficulties were developed which marred their full fruition.

There have been many earnest and able workers in this wide field of practical science, and it is only consistent with human frailty to find many of them inclined to consider their own efforts as having been principally conducive to achieved results, to the ignoring or undervaluing the just claims of foregoing or contemporary competitors. Parties outside of such questions can only judge from verifiable facts; and the general consideration, equally true of the practically-applied principles or their abstract scientific statement, that every great stride of improvement is at bottom the work of many minds; and, in most cases, the scientific principles are slowly evolved from tentative practical efforts, rather than improvements being a result of the application of those scientific principles.

Hence it is—while we may give all honour to those who, by dint of superior talent, or keener appreciation of circumstances, stand, as it were, victors in the conquered stronghold —we may glance retrospectively and generously on many victims, who, with true instinct, but adverse fortune, had striven manfully with the difficulties they encountered, and who in their very failure were useful as a warning and stepping-stone to those who followed. Clyde engineers know, and bear willing testimony to Mr J. M. Rowan's long-continued efforts in the direction indicated. It is, I think, forty years since he applied locomotive engineering to the paddle vessel "Telegraph"—an experiment brought to a tragical conclusion by the explosion of the boiler, with the effect of casting discredit upon any attempt to employ high pressures in marine practice for years, and doubtless leading Mr. Rowan to the consideration of boilers of a sectional or tubulous form in order to obtain high pressures, with less risk of disastrous explosions than the boiler-making of the period seemed to warrant.

Mr. J. M. Rowan had studied the application of high-pressure steam for long, and having concurred in certain views of Mr. Thomas Craddock, in 1856, in conjunction with the latter, he made an earnest attempt to carry them out in practice.

The views thus embodied, and the modifications and improvements which subsequently arose, having been fully given in Mr. Rowan's paper, and the merits and weaknesses of the system fully discussed by some of our eminent engineers, and published in the Transactions of the Institution of Engineers and Shipbuilders, need not be amplified by any remarks from me. But I will hazard a digression in reference to Mr. Thomas Craddock, an unfortunate man of genius, who, long before this, by every means in his power, had been striving unsuccessfully to get these views alluded to adopted, and carried out in practice. Had Mr. Craddock been somewhat less in advance of his time, had more clearly appreciated the mechanical difficulties to be surmounted, and cultivated the inventor's beatitude of expecting little with

the certainty of not being disappointed, he might have prospered. He only managed to get himself savagely criticised and ridiculed as a crack-brained enthusiast who had abandoned his own proper business to instruct the engineering fraternity in matters about which he knew nothing; and, wrapped up in his own sanguine views, and full of passionate self-assertion, poor Craddock probably annoyed and disgusted those who might have been disposed to listen to and assist him. That many of his plans have been whimsical and unpractical is doubtless true, but could the irony of fate be more strikingly illustrated than by a reference to the following portion of a critique on "Craddock's Universal Condensing Engine," from the *Artizan*, 1844, p. 104, in which we read:—"We have here a crop of those mechanical puerilities, the chief merit of which is that their folly is transparent. . . . . . We do not wish to practise any severity upon Mr. Craddock, for that would be cruel in the case of so primitive a personage; but there would be greater cruelty in leading him to suppose that he had found out anything of the least novelty and value. Let him therefore fortify himself at once to meet his doom; and at the same time remember that our judgment is a thing we cannot control, and is merely the exponent of public opinion." Then follows the judgment, from which I quote the following:—"But the most amusing part of Mr. Craddock's improvement is his scheme for working the two cylinders of a Woolfe's engine at right angles. . . . . He has devised a plan for making the steam pressure on the piston nearly twice as irregular as it would be in an engine of the common description! As the two pistons of a Woolfe's engine cannot be at the end of their respective strokes at the same time when their cranks are set at right angles, the difficulty presents itself when the steam cannot get away from the smaller cylinder during one half of the stroke, the larger cylinder not being at the time open for its reception. Mr. Craddock, however, gets over the difficulty by saying the steam will compress; and he actually proposes to compress the steam in the smaller cylinder into a very small volume and to let it in upon the

larger piston in this highly concentrated state; at the same time that he admits that to diminish the initial pressure on the larger piston is the only use or purpose of the second cylinder. Indeed, by Mr. Craddock's plan, the operation of the Woolfe engine is exactly reversed."

Thirty-five years having elapsed, in *The Engineer* of 17th October, 1879, I happened to read (in respect to the average pressures in the cylinder of a compound engine): "This calculation is easily made when engines work with cranks opposite each other. In practice, however, such engines are seldom met with. The cranks are always placed at some angle to each other, varying between 90 and 120 degrees; the former is the rule."

So that Craddock's "most amusing absurdity" of 1844 had become the rule of 1879. I have called this the irony of fate; but is it not pitiful that fate's iron heel should have trod so heavily on this poor man? More than a year ago I learned from a valued friend that Craddock—a broken and desolate old man—had lost an arm by an accident, and was in a state of destitution. An effort by some gentlemen to procure for him a small pension from Government had failed from want of sufficient influence, and an appeal to the engineering profession in his behalf had yielded no result!

"The destinies are opulent, and send here and there a man into the world to do work for which they do not mean to pay him in money, and they smite him beneficently with sore affliction, and blight his world all into grim frozen ruins round him . . and, in fact, have privately decided to reward him with beneficent death by-and-by, and not with money at all."

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When we reflect on the existence underlying ordinary mechanical phenomena, or its less understood manifestations in the phenomena of heat, light, and electricity; under the comprehensive idea that this existence must be a definite measurable quantity, we have a distinct perception that, to our senses, this is made up of two subsidiary ideas, and quantitatively may be viewed as the product of two factors.

It is customary to speak of one of these as *force*, the active agent which is effective through space, and we speak of the product of force and space, so many foot-pounds, as being the mechanical equivalent or measure of a given *vis viva*, *power*, or *energy*, a given quantity of heat, or any other term in which the underlying cause of the phenomena is implied, so far as it relates to mechanical effects.

But there is another and a better light in which to view these factors: to the first we attach the idea of *quantity*, and to the second the idea of *intensity*, whose conjoint product is the definite quantitative measure of the homogeneous entity, which is simplified to our senses by this division; for it must be remembered that we have no real knowledge of power or heat except when associated with matter, and that the true measure of these are not obvious surface phenomena, but require thoughtful consideration for their proper comprehension. Let us consider a piece of matter of weight, W, put into horizontal motion with the velocity V: from all experience it is known, in virtue of this movement, however it may have been communicated, the matter now possesses a capability of doing work which is named its *vis viva*, *power*, or *energy*, accordingly as we adopt the names proposed by Leibnitz, Smeaton, or Young, respectively, for this capability. The relation which obtains between its definite amount, E, and the elements involved, of which g, the intensity of gravity at the place, forms one, is,

$$E = \frac{W}{2g} V^2.$$

Now, this divides into two factors; the first, $\frac{W}{g}$, named the *mass* or quantity of matter, is invariable, and is the *quantity* factor; the remainder, $\frac{V^2}{2}$, varying directly as the square of V, is the *intensity* factor; so that the weight, which many would consider a perfectly definite phenomenon, is not a true measure of *quantity*, nor the observed velocity a measure of the *intensity*.

$E = \frac{W}{g} \frac{V^2}{2}$, however, is the true mechanical measure of the

underlying existence, in virtue of which the body will continue to move uniformly with the velocity, V; until, being expended upon something exterior to itself; or, by conversion into heat by friction within its own mass when arrested by some perfectly rigid obstacle, we have the matter at rest, at an increased temperature, which, properly estimated, is the exact equivalent of the power involved in the preceding sensible velocity.

But gravity has been mentioned—that mysterious effect of a still more mysterious existence, which, under the name of *the Æther*, is, so far as known, supposed to pervade space under enormous pressures; which, although an existence, seems to differ from material existence; and to movements and vibrations of different kinds within it, all the varied phenomena of heat, light, magnetism, and electricity are supposed to be due. In regard to *gravity*, however, the primary fact of the action of *the Æther* upon matter is that of its aggregating action; any two portions of matter when separated being seemingly impelled together with an *intensity* directly as the products of the quantities of matter in the masses, and inversely as the square of the distance between the average centres of those masses: these being denoted by $m_1$ and $m_2$ respectively, and the distance by d; in ordinary language, the force, F, with which they attract each other is,

$$F = \frac{m_1 m_2}{d^2}.$$

This relation holds good notwithstanding any conceivable difference between the masses, any distance between them, or any velocities with which the respective masses are moving; and, provided the distance between them remain invariable, *the Æther* does not in the slightest degree offer any obstacle to their movement, and thus it is that a body moving horizontally—that is to say, at an invariable distance from the earth's centre—provided the effect of the atmosphere were neutralized, would continue to move uniformly with any velocity once communicated to it.

Let us now consider this same piece of matter to ascend

vertically with the velocity, V; we know the aggregating tendency between it and the earth will instantly oppose this, and reduce the velocity somewhat, unless by expending power we neutralise this tendency, and allow the body to continue its upward flight with the uniform velocity due to the power expended upon it in giving it the velocity, V.

This is the *rationale* of the process of overcoming the force of gravity in the raising of a weight with uniform velocity: between a point, $H_2$, in its upward path, and another, $H_1$, still higher, the weight, W, ascending with uniform velocity, requires an amount of power expended in this interval whose mechanical measure is W $(H_1 - H_2)$ foot-pounds. This product of the force, W, into the space $(H_1 - H_2)$, or in a more correct sense, the *quantity* factor $(H_1 - H_2)$ into the *intensity* factor, W, are in strict reality but the surface phenomena of the homogeneous entity the quantity of heat which has disappeared from the power-developing agent, in direct proportion to the ascent of the weight, and this heat, uniformly distributed in the space interval, $H_1 - H_2$, upon something existing in that interval, has neutralized the gravitating action of *the Æther* in this space.

The usual mode of writing of this phenomena falls wide of the fact as it lies in Nature. Suppose we cease expending power, the weight will still ascend with diminishing velocity until the power inherent in the velocity has been expended in neutralizing *the Æther* in the further space of ascent; when all expended, the weight is an instant at rest; and if prevented from descending, after any interval of time, if we remove the impediment, will descend with an accumulated velocity mechanically equivalent to all the heat expended in its upward motion; and when brought to rest at the starting point, may be made to develop this heat in its own mass; or, by doing work during the descent, may have transferred it to another portion of the matter.

Heat is the fundamental fact in all movement, and the marine engineer, when taking diagrams, and by means of the small cylinder of his indicator, finds out from the average pressure in his cylinder, and space swept through by his

pistons, the power which is being developed; he, in reality and in a practical way, is determining the small proportion of the heat of his steam which is disappearing in it, previous to discharging it into the condenser. Of this small proportion a part goes to work the engine, another is wasted in friction, and if in undue quantity, much to his annoyance, becomes apparent in heated bearings; deducting these, the residue is to be found, outside the vessel, in various currents and movements in the water, which the vessel and her propeller displaces in their respective paths: generated currents change their direct movement into orbitual ones, which coalesce into waves, and after a short time subside, being dissipated by friction back into the heat which produced them. Nothing is created, nothing is annihilated; only a change: "that which hath been is now, and that which is to be hath already been," a fragment of old Chaldean philosophy upon which the whole science of mechanics is founded!

After this long preamble we reach the stage at which we confront that difficult problem—the law of the power-expenditure in the direct motion of steam vessels. It has been attempted in a plain way to show that the real fact in nature which we call expending power, is the disappearance of a quantity of heat mechanically equivalent to movements in the fluids displaced, and put in motion by the vessel's progress.

Of heat *by itself*, isolated from matter, we have no knowledge, and judge of its quantity by its effects upon the matter with which, in one form or another, it is always associated. We view it in the light of a definite homogeneous entity—*something which exists*, whose measure, to our limited perception, is a conjoint one of *quantity* and *intensity*, the one being capable of merging into the other; as, for example, when we mix a quantity of water at a given temperature with another quantity at a higher, the *quantity* and *intensity* of the heat in each becomes merged into the common quantity and intensity of heat in the joint mass.

Finally, reverting to Carnot's deduction, a definite amount of power, and a quantity of heat passing from a hot to a cold

body (mark Carnot's condition: "without bodies of unequal temperature being brought into contact," the fall of temperature being produced by doing external work) are quantities of the same nature, and may be substituted one for the other reciprocally; so that power developed and the necessarily equal work done (which is simply transferred power) are equally capable of being stated as the product of a *quantity* and *intensity* factor.

In a steam vessel's movements, we start with the reasonable proposition that the *quantity* factor will depend upon the vessel's actual dimensions, and the speed with which she is moving; and the first hypothesis adopted is, approximately, this may be taken as a factor of the form MV, where M and V are the immerged mid section and speed of the vessel respectively. The *intensity* factor, considering that the displacing movements of the vessel and propeller are proportionate to V, according to the statement of the law of *vis viva*, ought to be proportionate to $V^2$. The work done may be expected, therefore, to vary as the product $MV^3$, and the *power* doing it, as determined by the engineer, being denoted by E; the the ratio C of the first of these to the second, should be a measure of the efficiency of the same vessel at different speeds, and a comparative measure of the efficiency of different vessels when applied to their trial data. Hence the well-known formula—

$$(5) \qquad C = \frac{MV^3}{E}.$$

Usually interpreted as the product of the force $MV^2$ (the resistance) into the speed V (the space), which, divided by the power E, gives the efficiency co-efficient C.

It has been found, however, that this formula (and some proposed modifications) gives very irregular and contradictory results, and considerable experience and ability to draw correct inferences from conflicting data is needful for its practical application.

This is illustrated in the following Tables. In Nos. I. and II. are given the elements of four vessels, namely—Her

Majesty's composite screw vessel, "Shah," and despatch twin-screw vessel, "Iris;" the "Merkara," a merchant steamer by Messrs. Wm. Denny & Co.; and lastly, the "Charles Quint," by Messrs. A. & J. Inglis. The data of the two first will be found in the Admiralty Tables published last year; the "Merkara" data are an early example of Mr. Wm. Denny's careful and methodical mode of conducting progressive speed trials, now generally adopted; the "Charles Quint" is one of several vessels recently built for a French company, which, from published reports by the various builders—Messrs. Inglis, Elder & Co., and Caird—seem to have yielded very similar and most satisfactory results.

TABLE I.

| ELEMENTS OF VESSELS. | | | | | |
|---|---|---|---|---|---|
| Name, | "Shah." | "Iris." | "Merkara" | "Charles Quint." | |
| Length, . . | 334,8 | 300 | 369 | 313,6 | ft. in. |
| Breadth, . | 52,0 | 46,1 | 37,0 | 33,6 | " |
| Draft forward, | 21,6½ | 15,8 | 15,0 | 13,1 | " |
| " aft, . | 25,7½ | 20,6 | 17,6 | 16,6 | " |
| Mid area, . | 986 | 700 | 525 | 420 | sq. ft. |
| Displacement, | 5922 | 3290 | 3940 | 2478 | tons |
| Propeller, . | single | twin | single | single | screw |

TABLE II.

| Trial Data of Vessels. | | | | | |
|---|---|---|---|---|---|
| Vessel. | No. of Trial. | Power, Indicated Horses. | Speed, Nautical Miles. | Value of C $= \frac{MV^3}{E}$. | Value of C $= \frac{MV \text{ Log. } ^1 a V}{E}$. |
| "Shah," a = ·0792. | (5) | 7477 | 16·45 | 587·3 | 43·58 |
| | (6) | 2506 | 12·13 | 702·4 | 43·60 |
| | (7) | 772 | 8·01 | 656·3 | 44·10 |
| | (8) | 318 | 5·32 | 466·9 | 43·53 |
| "Iris," a = ·0750. | (14) | 7556 | 18·59 | 594·9 | 42·70 |
| | (15) | 3958 | 15·75 | 690·5 | 42·39 |
| | (16) | 1765 | 12·48 | 770·0 | 42·72 |
| | (17) | 596 | 8·32 | 676·7 | 41·12 |
| "Merkara," a = ·0735. | (1) | 1948 | 12·91 | 579·4 | 30·93 |
| | (2) | 1225 | 11·09 | 585·2 | 31·05 |
| | (3) | 718 | 9·10 | 551·0 | 31·12 |
| | (4) | 299 | 6·20 | 417·5 | 31·08 |
| "Charles Quint," a = ·0842. | (1) | 2062 | 15·11 | 702·8 | 57·21 |
| | (2) | 1318 | 13·42 | 770·4 | 57·33 |
| | (3) | 480 | 9·82 | 823·4 | 57·30 |

From the two last columns of Table II., it will be obvious that the great variations of the values of $C = \frac{MV^3}{E}$, in the

same vessel, at different speeds [for example, (6) of the "Shah" is 50 per cent. greater than (8), and in the "Iris" (16) is 30 per cent. greater than (14) in the same vessel]; if they really expressed comparative efficiency, could only do so for vessels at the same speed, for the co-efficient of a vessel at one speed bears very little relation to the same calculated for a different speed. It is therefore a most important step to show that these figures are nearly illusory, as is done in the last column, where, by substitution for the assumed *intensity* factor, $V^2$, a quantity most simply expressed by the symbol $\text{Log.}^{-1} aV$, which means the number whose common logarithm is the speed V multiplied by a small quantity a (the value of a generally lies between $\frac{1}{16}$ and $\frac{1}{8}$), we obtain a new co-efficient, whose variations in the same vessel fall within the limits of ordinary errors of observation. I shall not offer any formal investigation of a mathematical character, but will simply call your attention to an observation made by a singularly able man, not long since lost to science. The late Dr. Clerk Maxwell, in his Theory of Heat, page 289, when remarking on a kindred expression to the one given above for the *intensity* factor, writes: "We have already met with the same form in the case of heat diffused from a hot stratum by conduction. Whenever in physical phenomena some cause exists over which we have no control, and which produces a scattering of the particles of matter, a deviation of observations from the truth, or a diffusion of velocity, or of heat, mathematical expressions of this exponential form are sure to make their appearance."

Referring to the last column of Table II., you will see the variations of the co-efficients of the respective vessels, from the average values—say, 43·7, 42·2, 31, and 57·3—are trifling; and the next question is, whether the factor M is a proper expression of the vessel's dimensions as affecting the *quantity* factor in comparing different vessels? Looking at the respective displacements and mid areas, we at once conclude that this is not the case. In the "Shah" and the "Charles Quint," for each square foot of mid area we have 6 tons of

displacement; in the "Merkara" this proportion rises to 8; but in the "Iris" is only about 4·7; and since displacement, not mid area, is the commercially valuable element, some other mode of viewing the question would seem to be necessary. Displacement alone is not a proper factor, as, in that case, similar vessels having their displacement as the cube of a lineal dimension (breadth, for example), the efficiency co-efficients would increase in the ratio of the breadth very nearly. Hence, when employing the displacement as a factor, we take the two-third power as in the usual formula, $C = \frac{D^{\frac{2}{3}} V}{E}$; which, in effect, assumes the vessels to be similar in form but of a lineal dimension which answers to the given displacement.

By this last formula, the co-efficients from experiments on the same vessel, have the same ratio to another as those by the midship area formula; but they differ in comparing vessels with one another, and are generally more trustworthy.

In the following Table, III., is given the value of the co-efficient $C = \frac{D^{\frac{2}{3}} V^3}{E}$, and the values when the *intensity* factor is corrected by writing $\text{Log}^{-1} aV$, instead of $V^2$. (The values of E and V correspond to those in Table II.)

TABLE III.

| Vessel. | No of Trial. | Value of C $= \frac{D^{\frac{2}{3}} V^3}{E}$. | Value of C. $= \frac{D^{\frac{2}{3}} V \text{ Log.}^{-1} aV}{E}$. |
|---|---|---|---|
| "Shah," a = ·0792. | (5) | 194·9 | 14·47 |
| | (6) | 233·1 | 14·48 |
| | (7) | 218·0 | 14·64 |
| | (8) | 155·3 | 14·46 |

TABLE III.—*Continued.*

| Vessel. | No. of Trial. | Value of C $=\frac{D^{\frac{2}{3}}V^3}{E}$. | Value of C $=\frac{D^{\frac{2}{3}}V \text{ Log.}^{-1} aV}{E}$. |
|---|---|---|---|
| "Iris," a = ·0750. | (14) | 188·1 | 13·56 |
| | (15) | 218·4 | 13·36 |
| | (16) | 243·6 | 13·50 |
| | (17) | 213·8 | 13·00 |
| "Merkara," a = ·0735. | (1) | 275·9 | 14·72 |
| | (2) | 278·1 | 14·78 |
| | (3) | 262·1 | 14·77 |
| | (4) | 199·0 | 14·79 |
| "Charles Quint." a = ·0842. | (1) | 306·4 | 24·94 |
| | (2) | 335·9 | 25·00 |
| | (3) | 359·0 | 24·98 |

Here, as in the former case, large variations are shown in the same vessel, which are absent from the values with the corrected *intensity* factor given in the last column, the average values for the different vessels may be taken at 14·5, 13·5, 14·75, and 25·0 respectively; which, taking the displacement into account, seems to be more practical comparative figures, but a strict comparison requires the *intensity* co-efficients to be brought to a common standard, which is effected by dividing each of these co-efficients by the number whose logarithm is the product of any assumed speed of which the vessels are capable into the difference between the lowest *intensity* co-efficient and the higher ones.

Thus, for the values of the efficiency co-efficients of these vessels by the midship area formula, the displacement to the power two-third formula, and this latter reduced to a common intensity ·0735V (that of the "Merkara"), when the speed in each is 13 knots, we have—

| Efficiency co-efficients | "Shah" | "Iris." | "Merkara." | "Charles Quint." |
|---|---|---|---|---|
| Mid Area Formula, | 43·7 | 42·2 | 31·0 | 57·3 |
| Displacement do., | 14·5 | 13·5 | 14·75 | 25·0 |
| Do. at 13 Knots, | 12·3 | 12·91 | 14·75 | 18·15 |

The "Merkara's" co-efficient is unchanged, but the others are reduced, and these numbers are the relative efficiencies at 13-knot speed, when the two-third power of the displacement is assumed as the element of the vessels' dimensions which affects the quantity factor.

In a scientific point of view, the first step is to leave out the special dimensions element, and express the relation between the power and speed for each vessel by an equation of the general form $E = bV \text{ Log.}^{-1} aV$, where bV is the *quantity* factor, and $\text{Log.}^{-1} aV$ the *intensity* factor. For the vessels referred to, the quantities b and a have the special values in the following equations:—

| | |
|---|---|
| "Shah," . . | $E = 22{\cdot}63 \text{ V Log.}^{-1} {\cdot}0792 \text{ V.}$ |
| "Iris," .. . | " $= 16{\cdot}30 \text{ V Log.}^{-1} {\cdot}0750 \text{ V.}$ |
| "Merkara," . | " $= 16{\cdot}90 \text{ V Log.}^{-1} {\cdot}0735 \text{ V.}$ |
| "Charles Quint," | " $= 7{\cdot}30 \text{ V Log.}^{-1} {\cdot}0842 \text{ V.}$ |

By which, a simple calculation gives the power E for an assumed speed V.

Supposing steam vessels of exactly similar form but of different dimensions and proportionately immerged; then, any line l in one is represented by a line l r in another, where r is named the linear ratio; and the mathematical truth is

involved that the expression $L\sqrt{M}$, or product of the length into the square root of the immerged mid area, in the two vessels, is in the proportion of 1 to $r^2$; which is equally the proportion which the immerged mid areas, or surfaces of hull, bear to each other. Many eminent authorities have adopted the immerged surface of the hull as the proper factor for the vessel's dimensions. The late Dr. Rankine proposed a formula with this quantity, augmented by a particular function of the water line angles, as the true factor in the power formula; but this is erroneous, for two important reasons: first, it retained the $V^2$ intensity factor, and consequently the great and anomalous variations which this introduces into the question are not eliminated; secondly, in contradiction to the earlier and more correct views of Poncelet, it attached undue importance to the surface friction on the hulls, to the entire ignoring the principal movement produced in the water by the vessel's progress—namely, the sternward flow of the displaced water. The power involved in this, recent writers describe as "producing waves," not recognising that these waves are but an after-effect of the power involved in this current, which is not, as alleged, superadded to—first, power expended on a resistance principally friction of machinery and hull; secondly, to expenditure on a resistance proportional to the square of the velocity so that the whole finally rises by unknown laws to the third, fourth, or higher powers of the velocity in virtue of those produced waves. So long as the circumstances remain the same, one simple law governs the whole power-expenditure; and, instead of augmented surface, contracted section seems to be a nearer approach to the actual fact. For example, similar vessels with dimensions in the linear ratio 2, 1, and $\frac{1}{2}$, have the products of length and square root of mid area, in the ratios of 4, 1, and $\frac{1}{4}$ precisely that of their mid areas. But it is a known fact, where there is proportionate depth of water, a similar vessel of four times the mid area will not take four times the power for the same speed, and one of one-fourth the area will take more than one-fourth the power. Hence a formula framed on the square of a lineal

dimension when applied to similar vessels, requires a correction to place all these vessels tested by it on the same footing. The seven-eighth power of the square of this ratio is a fair and easily-applied correction, and in the cases 4, 1, and ·25 we have supposed, would reduce these to 3·363, 1, and ·297; the first being 10 per cent. less, and the last 20 per cent. greater, than either the midship area, displacement, or immerged surface formulas would give in these cases.

This is the reason of the fractional power in the formula proposed some time ago, in which the efficiency co-efficient (for distinction denoted by $C_1$),

$$C_1 = \frac{(L\sqrt{M})^{\frac{7}{8}} \text{ V Log.}^{-1} \text{ aV.}}{E}$$

But, in the case where vessels are very dissimilar—say, in comparing short, broad, shallow vessels with long, narrow, and deep draft ones—the formula which places them on a fairer comparative footing is—

$$C_2 = \frac{(L^{\frac{7}{8}}\sqrt{M}\ B^{\frac{1}{8}}}{E} \text{ V Log.}^{-} \text{ aV.}$$

And we may contrast the values given by these with those for the four vessels by the mid area and displacement formulas.

| Vessel. | Value a | $C_1$ | $C_2$ |
|---|---|---|---|
| "Shah," . . . | ·0792 | 145·7 | 367·3 |
| "Iris," . . . | ·0750 | 157·0 | 383·0 |
| "Merkara," . . | ·0735 | 161·4 | 374·4 |
| "Charles Quint," | ·0842 | 294·1 | 664·1 |

Now, to compare these, we must reduce to a common intensity—say a = ·0735, and take a speed of which all are capable—say V = 13, which gives the following; the second figures in each column denoting the ratios to the greatest and comparative efficiencies at this speed.

COMPARATIVE VALUES OF EFFICIENCY CO-EFFICIENTS WITH DIFFERENT FACTORS AT 13 KNOTS SPEED.

| Vessel. | M | | $D^{\frac{2}{3}}$ | | $(L\sqrt{M})^{\frac{2}{3}}$ | | $(L^{\frac{2}{3}}\sqrt{M})\ B^{\frac{1}{6}}$ | |
|---|---|---|---|---|---|---|---|---|
| "Shah," . | 37·10 | ·892 | 12·30 | ·678 | 122·9 | ·605 | 309·7 | ·642 |
| "Iris," . | 40·35 | ·970 | 12·91 | ·711 | 150·1 | ·739 | 366·2 | ·760 |
| "Merkara," | 31·00 | ·745 | 14·75 | ·812 | 161·4 | ·794 | 374·4 | ·778 |
| "Charles Quint," | 41·60 | 1·000 | 18·15 | 1·000 | 203·2 | 1·000 | 482·1 | 1·000 |

To conclude with a more extended view of the application of this last formula: in the following Table, IV., is given the intensity co-efficients and construction elements of eight vessels of the Royal Navy. In the "Iris," two sets of trials with different screws show entirely different results; also, the "Merkara" and "Charles Quint," all arranged in order of the values of the intensity co-efficient. Under these, separated by a line, are the very interesting results of a trial of one of Messrs. Yarrow & Co.'s fast torpedo boats, as published in *Engineering* towards the close of 1879, and the data of the "Livadia's" trials, as published in the *Times* by Sir E. J. Reed, M.P.

In Table V. is given, first, the corresponding general values of $C_2$ corresponding to the foregoing intensity co-efficients, and then, to give a more definite comparison, the intensities being reduced to one uniform value ·0842 (that of the "Charles Quint") the corresponding values of the efficiency co-efficient for 10, 13, 15, and 18·5 knots are tabulated. In each case, the speed is only carried so far as warranted by actual trial; thus we stop the "Merkara" and "Comus" at 13 knots, and the gunboat "Firebrand" and the river gunboats of the "Medina" type at 10 knots, these being the practical limit of speed for these vessels. The numbers in each column are then a very approximate measure of the comparative efficiency of the respective vessels, in respect to the relation of speed and displacement.

From this point of view, the long, narrow, deep draft, fine vessels, are far superior to short, broad, shallow draft vessels.

The increased efficiency of the low intensity type of vessels at high speeds opens up a most interesting field of inquiry; and the curious changes in quantity and intensity shown by the torpedo boat and "Livadia," would form another most interesting topic, but it is impossible to advert any further to them on this occasion.

TABLE IV.—Trial Values of Intensity Co-efficient, and Construction Elements of Steam Vessels.

| Name. | Value of a. | Length L. | Breadth B. | Mid area M. | Displacement. D. |
|---|---|---|---|---|---|
| "Iris" (second trials), . | ·0707 | 300 | 46·1 | 700 | 3290 |
| "Merkara," . . . . | ·0735 | 368 | 37·0 | 525 | 3940 |
| "Iris" (fourth trials), . | ·0750 | 300 | 46·1 | 700 | 3290 |
| "Shah," . . . . . | ·0792 | 334 | 52·0 | 986 | 5922 |
| "Euryalus," . . . . | ·0810 | 280 | 45·5 | 802 | 4223 |
| "Jumna," . . . . | ·0833 | 360 | 49·1 | 830 | 6015 |
| "Charles Quint," . . | ·0842 | 313 | 33·5 | 420 | 2478 |
| "Comus," . . . . . | ·0920 | 225 | 44·5 | 583 | 2264 |
| "Bacchante," . . . . | ·1005 | 280 | 45.5 | 785 | 4126 |
| River Gunboats, . . . | ·1100 | 110 | 34·0 | 175 | 360 |
| "Firebrand," | ·1380 | 125 | 23·5 | 198 | 452 |
| Torpedo Boat, . . . | ·0700 | 86 | 9·5 | 20·5 | 27 |
| „ above 17 knots, | ·0606 | „ | „ | „ | „ |
| "Livadia," . . . . | ·0670 | 230 | 153·0 | 1000 | 4420 |
| „ above 14 knots? | ·0680 | „ | „ | „ | „ |

TABLE V.—Values of Co-efficient $C_2$ for Trial Intensities; and Calculated Values of same for definite speeds, with Intensity Co-efficient assumed at ·0842.

| Name. | $C_2$ | 10 knots | 13 knots | 15 knots | 18·5 knots. |
|---|---|---|---|---|---|
| "Iris" (second trials), . | 292·7 | 399·4 | 438·4 | 466·5 | |
| "Merkara," . . . | 374·4 | 479·0 | 517·8 | | |
| "Iris" (fourth trials), . | 383·0 | 473·4 | 504·4 | 526·3 | 566·8 |
| "Shah," . . . . . | 367·3 | 412·1 | 426·6 | 436·6 | |
| "Euryalus," . . . . | 283·4 | 305·0 | 311·8 | 316·5 | |
| "Jumna," . . . . . | 399·5 | 407·9 | 410·4 | 412·1 | |
| "Charles Quint," . . . | 664·1 | 664·1 | 664·1 | 664·1 | |
| "Comus," . . . . . | 362·8 | 303·2 | 287·3 | | |
| "Bacchante," . . . . | 566·9 | 389·5 | 348·0 | 322·8 | |
| River Gunboats, . . . | 377·8 | 208·5 | | | |
| "Firebrand," . . . . | 803·2 | 232·7 | | | |
| Torpedo Boat, . . . . | 332·2 | 460·7 | 508·2 | 542·5 | |
| " above 17 knots, | 234·4 | " | " | " | 640·5 |
| "Livadia," . . . . . | 139·9 | 207·7 | 234·8 | | |
| " above 14 knots? | 108·4 | " | " | 189·6 | |

# ON LIGHTHOUSE CHARACTERISTICS.

By Sir WILLIAM THOMSON, D.C.L., F.R.S.

*ON FRIDAY, 11th FEBRUARY, 1881.*

For a lighthouse to fulfil the reason of its existence, it must not only be seen, it must be recognised when seen. If seen, and not known, a lighthouse is of no use; if not seen, it certainly could not be of use. There has been a great amount of discussion as to what is the primary and most important quality of a lighthouse. Penetrative power—to allow the light to be seen in thick weather at as great a distance as possible—is, of course, the first object to be striven for. The next question is—How to make use of a lighthouse when seen? If a sailor, descrying a lighthouse from a great distance, is in doubt whether the light is on a fishing-boat a mile off, or on the masthead of a steamer three miles off, or on a lighthouse six miles off, it is obvious that the lighthouse, in merely letting its light be seen, had achieved but a small part of the task to be achieved. I do not want to take the ungracious part,—of criticising or saying anything has been done less well than it should be done; nor do I want to be behind in expressing my cordial and most sincere admiration of the great work which has been done for the world by the lighthouse boards of this country—by the Trinity Board, the Board of Northern Lights, the Commissioners of Irish Lights, and,—not least in intensity, if not so great as the others in quantity, of good done,—by the Clyde Navigation Trustees. But I must say that there has not been among lighthouse authorities hitherto quite enough of determination to make the very most of the

distinctive character, and the possibilities of giving a distinctive character, to their lights that science and commonsense placed before them. There is too much, perhaps, of the idea of saving oil, or of making a certain quantity of oil go a great way, and not quite enough of the idea that the object of the lighthouse after all is to be known, and that to be seen without being known is not enough. The question to be considered is how to know one light from another—how to know a light descried just above the horizon, and dipping now below the horizon, lost sight of for a quarter of a minute, again seen, lost for a little time, and again seen continuously—to recognise it with certainty, and without loss of time, in such circumstances. The Hollywood Bank Light in Belfast Lough, the leading light for vessels entering the Lough, is so recognised, being a short-short-long eclipsing light. The Copeland Light, off the south entrance of Belfast Lough, is not recognisable by any distinguishing characteristic, being merely a fixed light. It has, however, I am informed, been determined by the Commissioners of Irish Lights to alter it, and give it a distinctive character. I take those two cases because, when a celebrated lighthouse engineer was with me on one occasion in my yacht, approaching Belfast in the small hours of a summer morning, we had just that experience of them both. I said to him, "Look at that light, and tell me what it is; is it a masthead light, or what is it?" He could not tell. It was the Copeland Light, as we learned soon afterwards from our position. My friend fully admitted after that, what he never admitted before—namely, that it was possible to confound a lighthouse light with a light on a steamer's masthead; and soon after, the Hollywood Bank, barely visible ten miles off, was recognised by its short-short-long within a quarter of a minute of its being first seen, and gave a triumphant proof of the practical value of its distinctive character.

With reference to the description of lights and their distinctions in lighthouses, there is, in the first place, to be considered the character of the light, and the appliances for economizing of it. The old coal fire on the cliff, which was the first lighthouse, was a relic of the past, which would never

now be set up for the purpose of marking a point on the coast; yet, practically, where there are blazing furnaces at ironworks, as on the Ayrshire coast in the neighbourhood of Ardrossan, these same fires do constitute very important, though undesigned, marks by which a mariner discovers his position. The substitution of economical lamps, in which a great deal of light was given with a moderate consumption of fuel, took the place of the coal fires on the cliffs. Then reflectors were introduced. A great invention was made early this century, which led to the now prevailing dioptric system. It is perfectly clear that the great brilliance and success in economizing the fuel of the flames in the lighthouses of the present day is directly due to the invention of the dioptric system; and has been largely promoted by the great use made of it, and the great improvements effected on it, by Messrs. Stevenson, the engineers of Northern Lights. Then came the question of how to economize light when not wanted to show all round, as, for instance, in the case of the Lamlash light, which shows a brilliant light seaward, and a moderately-bright light over the bay of Lamlash. The occulting light shown by the Messrs. Stevenson in our present Exhibition is a light fulfilling one of the conditions of characteristic quality, with very perfect economy of light. The very principle by which light was economized has given one of the first lighthouse characteristics in the ordinary revolving light. Not content with condensing the light to the horizon so as to shed itself out in all horizontal directions, engineers condensed it into certain fixed directions for special reasons. Sometimes they condensed the light into a ray, for the reason of sending it in the direction of a particular channel: sometimes for the sake of giving greater intensity than they could practically attain otherwise, and then they made the ray revolve so as to shed its brightness all round the horizon in the period of its revolution. A policeman's bull's-eye lantern is an instance in point. There is a greater intensity of light in a ray from an ordinary bull's-eye lantern than a light of anything like the same power could give without that optical appliance, or something equivalent to it, or more perfect than it.

Besides its light, a modern lighthouse generally contains also, for use in such thick or foggy weather that the light cannot be seen, a sound-making appliance, the object of which is not only to be heard, but when heard to be immediately recognised to be itself and nothing else. Mr. Price Edwards, in his communication to the Society of Arts, of 15th December last, on "Signalling by means of Sound," gave an interesting and clear description of the chief practical methods hitherto in use for this exceedingly important addition to the efficiency of lighthouses; and I shall have occasion to return to the subject of characteristic sounds in relation to the several methods which have been adopted to give characteristic qualities to the light itself of a lighthouse.

Setting aside colour—now generally admitted to be indefensible, as a distinction for lighthouse lights, except in the proper use of it, which is to distinguish different directions of the light by coloured sectors to mark rocks or other dangers, or the safe limits of navigable channels—we find all the characteristic qualities of lighthouses to come under one or other of the following three descriptions:—

I. Flashing lights.
II. Fixed lights.
III. Occulting or eclipsing lights.

The well-known name "Revolving lights" is habitually limited to flashing lights; but it is liable to ambiguity, because the same revolving mechanism is also applied in many cases to produce the eclipses of "Occulting or Eclipsing lights." The official description of the revolving light in the "Admiralty List of Lights," is as follows:—

"*Rev.*—Revolving light, gradually increasing to full effect, then decreasing to eclipse. [At short distances and in clear weather a faint continuous light may be observed.]"

This, in fact, includes the description of the flashing light:—

"*Fl.*—Flashing—showing flashes at short intervals, or groups of flashes at regular intervals."

A combination of the fixed and flashing qualities, though

comparatively rare, constitutes an important characteristic light, described in the Admiralty list as follows:—

"*F. and Fl.*—Fixed light with addition of white or coloured flashes, preceded and followed by a short eclipse."

Thus we have really very little of complexity in the fundamental classification into the three descriptions of Flashing, Fixed, and Occulting.

In the flashing light, the light is visible for only a short time—a fraction of a second, or from that to five or six seconds—and then disappears; and, for a much longer time than the duration of the flash, it remains invisible, until it again flashes out as before. In the fixed light there is no distinguishing characteristic whatever, but merely a light seen shining continuously and uniformly. The occulting light is visible during the greater part of its time like a fixed light, shining continuously and uniformly. Characteristic distinction is given by a short eclipse, or by a very rapid group of two or three short eclipses, or of short and longer eclipses recurring at regular periods, "flashes of darkness," as they have been called, cutting out, as it were, from the light its mark, by which it may be distinguished and recognised to be itself and nothing else, in the very short time (from half-second at the least, to seven seconds at the most) occupied by the group of eclipses.

### I.—Flashing Lights.

Six years ago, in every flashing light there was just one flash in the period, and thus the length of the period was the sole distinction between one flashing light and another. Thus, in the "Admiralty List of Lights for the British Islands" for 1875, we find about 100 flashing lights of different periods, from the four-seconds' period of Ardrossan Breakwater light to the two-minutes' period of the upper light of Lundy Island, of the South Stack, Holyhead, and of one of the lights on Slyne Head, off the west coast of Ireland; and the distinction of each one of these 100 lights was solely its period as a simple flashing light, except in cases in which the objectionable distinction by colour was put in requisition.

When it was determined to choose periods the same, or nearly the same, for neighbouring lights, it was found necessary to add distinction by colour, objectionable as this is if not enforced by necessity. Thus, for example, the Gull Stream lightship, in the fairway between the Goodwin Sands and the Kentish coast, is a revolving light of twenty seconds' period, while the East Goodwin lightship, about six miles from it, is a revolving light of fifteen seconds' period. Without greater accuracy than is generally to be found in the time-keeping of flashing lights, even on shore, the distinction between fifteen and twenty seconds could scarcely be relied upon, as given by the mechanism; and even if given trustworthily by the mechanism, the distinction could only be discovered by the sailor with certainty by the aid of a chronometer, the use of which is out of the question as a practical means for recognising a light when seen. To give a sufficient distinction between these two lights, therefore, it was found necessary to use colour; the East Goodwin was made green, the Gull Stream white. Again, the St. Agnes light, Scilly, and the light on the Wolf Rock, two far outlying lights, about twenty miles asunder, are each of them of half a minute period from flash to flash, and the sole distinction between them is that the flashes of the Wolf light are alternately white and red, while those of the St. Agnes' light are all white.

The insufficiency of the distinction of flashing lights, merely by length of period, had come to be felt so strongly that a very important fresh distinction was introduced in 1875, in the lightship then first placed on the Royal Sovereign shoal; the Group Flashing Light of Mr. Hopkinson, in which, instead of just one flash in the period, there are, in the case of the Royal Sovereign light, three flashes in the period, or, as may be in other cases, two flashes, or four flashes, the interval between the successive flashes of the group being much shorter than the interval from group to group in the whole period. In two cases in the English Channel, the North Sand Head and the Casquets, the new triple flashing light was introduced to replace, by a group of three flashes

in rapid succession, three separate lights which had been the characteristic arrangement previously; three fixed lights in the case of the North Sand Head, and three simple flashing lights in the case of the Casquets.

Mr. Preece has imprudently pointed out that Mr. Hopkinson's triple flashing light is the letter S of the Morse-Colomb flashing alphabet. Sailors, we may hope, are happily ignorant of this truth, otherwise the proverbial captain of the collier would be calling out to his chief officer—"Bill, was that a S, or a I, or a H, or a E?" Bill, if he was well up in dramatic literature, would reply, "Captain, them is things as no fellow can understand." I must say, however, that I agree with Mr. Preece, and think that, while many may find memory aided, none can be embarrassed by an official statement of the Morse letter corresponding to any group of flashes or eclipses that may be chosen as the characteristic for any particular light. This, however, is a matter of comparatively small moment at present. The great thing is to find how lights may be most surely and inexpensively rendered distinctive, so that no sailor, educated or uneducated, highly intelligent or only intelligent enough to sail a collier through gales, and snowstorms, and fogs, all winter, between Newcastle and Plymouth, may know each light as soon as he sees it, without doubt or hesitation.

This object is fully attained by the triple flashing light, if quick enough. The triple flashing light of the Casquets, and of Bull Point (Bristol Channel), which are the quickest of the kind hitherto made, complete their three flashes in twelve seconds, after which there is an interval of eighteen seconds of darkness. These are, no doubt, very admirable and thoroughly distinctive lights; but it would be very much better if they were made three times as fast, which, with the existing machinery, could, I believe, be easily done. If this were done they would show their flashes each in two-thirds of a second, and with only a second of time between. Thus, the three flashes completed in four seconds would be instantly recognised as a group of three, without the necessity of any counting either of flashes or of numbers of seconds of time in

the intervals between the flashes; and, instead of having to wait in darkness for eighteen seconds, the sailor would only have to wait six seconds for a repetition of the triple flash.

The *Royal Sovereign*, the *Seven Stones*, the *Newarp* (near Yarmouth, on the east coast), and the *Saltees* (off the south coast of Ireland), all lightships supplied within the last few years with the Triple Flashing Light, are each of them of one minute period, of which there is thirty-six seconds of darkness, and twenty-four seconds of flashing. These lights are all too slow to do full advantage to the triple flash system. When one of them is first seen, it is very apt to be confounded with an ordinary "revolving light"—that is, a single-flash flashing light. Even somewhat careful watching —at all events if the weather or the distance from the light be such as to leave any room for doubt—does not always immediately resolve the doubt. A sixfold quickening of each of these lights would greatly enhance its distinctive quality, and would make it really fulfil the condition pointed out by the Elder Brethren of the Trinity House, as the object to be aimed at in every modern lighthouse, "That he that runs may read."

The satisfactory distinctions of group-flashing lights are exhausted in the groups of two or three or four flashes; because, to count five or six, or more, would be embarrassing, and liable to mistake at sea. It has been proposed to obtain further distinction by using groups of longer and shorter flashes, as in Captain Colomb's Flashing Telegraph, now in general use, and very thoroughly appreciated both in the Navy and in the Army; but there are optical difficulties in the way of making, with satisfactory economy, groups of long and short flashes, separated by short intervals of darkness in the group, and comparatively long intervals of darkness between successive groups; and considering how very much more useful and satisfactory at sea is a lighthouse showing long light with short intervals of darkness than even the quickest of flashing lights, it does not seem desirable to push the distinctions of flashing lights further than the double, triple, and quadruple groups. The periods for these lights which

seem best adapted for practical purposes, all things considered, but most particularly their value to the sailor, are as follows:—

| Number of flashes in period. | Duration of each flash. | Duration of group. | Whole period. |
|---|---|---|---|
| One............... | $\frac{1}{4}$ sec. | $\frac{1}{4}$ sec. | 2 sec. |
| One............... | 1 " | 1 " | 8 " |
| Two............... | $\frac{1}{2}$ " | 2 " | 6 " |
| Two............... | 1 " | 4 " | 12 " |
| Three............ | $\frac{1}{2}$ " | $3\frac{1}{2}$ " | 9 " |
| Four.............. | $\frac{1}{4}$ " | $2\frac{1}{2}$ " | 8 " |

It may be objected to the suggestions of the preceding table, that the quarter-second flashes are too short to be perceived with the same certainty as flashes of five or six seconds' duration. Experiment alone can answer decisively the question whether, with equal maximum brilliancy in each flash, a flash of quarter-second duration recurring every two seconds, or one of half-second recurring every four seconds, or one of one second recurring every eight seconds, is the most easily to be seen at a great distance or in hazy weather. From physiological experiments already made, it has been concluded that one-tenth of a second is a long enough time to fully excite the sensibility and perceptive power of the eye, and it seems probable that rapidity of recurrence of the contrasts between light and darkness will give a positive advantage to the quicker flash in respect to perceptibility, even when the observer knows in what direction to look for the light; and when he does not know exactly in what direction to look, which is the practical case of a sailor at sea trying to pick up a light, shortness of the time of invisibility is of supreme importance. All things considered, it seems most probable that the quarter-second flash recurring every two seconds will be very much more easily and surely picked up practically at sea than a flash of one second recurring every eight seconds.

Before passing from this subject of flashing lights, I may

be allowed to say that I first received my impression of the vital importance of quickness in a light from a very practical man—the man who, in 1866, showed us within a quarter of a mile, in mid-ocean, where to find the cable which had been laid and lost in 1865—Captain Moriarty, R.N. I well remember when on one occasion, either in 1858 or 1865, I do not know which, in making the Irish coast in dirty weather, he said—

"Those lighthouses should flash out their characters like your electric signals; every lighthouse should flash, and flash, and flash, many times in a minute, showing you which lighthouse it is every time. That long minute of the revolving light has often seemed to me like an age, when I have been anxious to make out where we were in a gale of wind and rain."

## II.—Fixed Lights.

Of the 623 lights numbered in the "Admiralty List of Lights for the British Islands for 1881," 490 are fixed, 112 are flashing, and 21 are occulting (or "eclipsing," or "intermittent"); and similar proportions are to be found in the official list of lights for other parts of the world. Thus it appears that fixed lights constitute the great majority. The fixed light has a great advantage in respect to practical usefulness over the flashing light, in being always visible. The superior brilliancy produced by optical condensation of the revolving light is, in some respects, dearly bought economy, when the great diminution of usefulness to the sailor, in its comparatively long periods of darkness, is taken into account. Theorists who praise the revolving light unqualifiedly for its superior penetrative power, seem to forget the counterpart in optics to the great principle in dynamics—that which is gained in power is lost in speed: in flashing lights, what is gained in brilliancy is lost in time of visibility. The painfully anxious scanning of the horizon for a one-minute flashing light, is known to every one who has ever had occasion to look for one in practical navigation; and the comparative ease of picking up a fixed light, and keeping sight of it when

it is found, in difficult circumstances, is thoroughly appreciated at sea by sailors. Still, if the revolving light can be seen at all, whatever be the difficulty in picking it up, and whatever the annoyance of losing sight of it and having to pick it up again, it has fulfilled the object of a lighthouse. All are agreed in the maxim that "the grand requisite of all sea lights is penetrative power;" and if the fixed light cannot be seen at a distance, or in weather in which the revolving light is seen, the fixed light has failed, and the revolving light has done its work for the occasion. It depends very much on the special circumstances whether the same quantity of light, given out uniformly as a fixed light, or condensed and given out in flashes, with comparatively long intervals of darkness, as in the revolving light, is better in respect to being seen. In stormy or variable weather, with heavy showers of rain or snow, the fixed light is much safer than a one-minute revolving light of much greater absolute brilliancy; as several successive flashes of the revolving light may be lost through passing showers, while the fixed light loses no chance of being seen in intervals between the showers. On the other hand, in hazy or foggy weather of tolerably steady character, a revolving light can be seen efficiently at a greater distance than the same absolute quantity of light, given out uniformly as a fixed light.

In the question of economy, the great first cost of the optical apparatus, special to the revolving light, must be set against the greater consumption of oil, or gas, or fuel, to obtain in a fixed light, whether it be an oil or gas lamp, or an electric light, the same brilliancy. In many cases, indeed, the interest of the money spent on prisms, and lenses, and mechanism in the revolving light, and in some of the most beautiful and perfect of the appliances for the azimuthal condensation of fixed lights, would supply the oil required to give the same, or nearly the same, brilliancy all round the horizon. These circumstances are, of course, all to be taken into account by the proper authorities in respect to every project for a new lighthouse. But we have actually at present the great fact of 490 fixed lights on the coasts of the British

Islands; and when it is considered desirable or necessary to give more brilliancy to any of them, this certainly is not to be done by converting it into a flashing light, but by making it a more powerful oil or gas light, or converting it into an electric light. Indeed, after Mr. Douglas's communication of two years ago (March 25th, 1879) to the Institution of Civil Engineers, on "The Electric Light Applied to Lighthouse Illumination," and the discussion which followed upon it, and considering the great progress which has been made since that time in lighting by electricity, we can scarcely doubt that, in the course of a few years, nothing but the electric light will be thought of for any new lighthouse of great importance.

The great defect of fixed lights at present is the want of characteristic quality by which the sailor, when he sees a light which really is a lighthouse light, may immediately feel sure that it is so, and not a steamer's mast-head light, nor a trawler's or fishing-boat's light, nor a light on shore other than a lighthouse light; and that knowing it to be a lighthouse, he may know exactly which of two or more possible lighthouses it is. The need for thorough-going remedial measures to remove this defect has been more and more felt of late years, and is now very generally admitted. Unless a second light is to be added, or the generally objectionable expedient of colour for distinction is in any particular case to be admitted, the only systematic means of giving characteristic quality to a fixed light is by means of occultations or eclipses; and hence the origin of the "Occulting" or "Eclipsing light." We may accordingly look forward to all, or nearly all, the important fixed lights of our coast being, without any very long delay, converted into lights of this class. It is satisfactory to find that during the last year the Elder Brethren of the Trinity House converted one most important light, that of the North Foreland, and another very important one, the light on the west end of Plymouth Breakwater, into eclipsing lights, and that a similar improvement has been promised for five more of the fixed lights under their charge (Mucking, Lowestoft, Chapman, Flatholm, and Evan) within the official year 1880-1.

## Occulting Lights of the British Islands, 1881.

| No. | Name. | Place. | Period. | Remarks. |
|---|---|---|---|---|
| 12 | Plymouth | On W. end of breakwater | Half-minute. | The light suddenly disappears for 3 seconds every half-minute. |
| 107 | North Foreland | On head | ,, | The light suddenly disappears for 5 seconds every half-minute. |
| 282 | Tarbet Ness | 430 yards from the extremity of the point | 3 minutes. | Visible 2½ minutes, eclipsed ½ minute. |
| 305 | Ru Stoer | South ear of Ru Stoer | 1½ ,, | ,, 1 ,, ,, ½ ,, |
| 315 | Hebrides, Barra Head | Highest part of Bernera Island, South point of the Hebrides | 3 ,, | ,, 2½ ,, ,, ½ ,, |
| 339A | Craigmore, Firth of Clyde | End of pier, Bogany point, Bute Island | 11 seconds. | Five seconds of light, followed by four eclipses, long-short-long-short. |
| 347 | Greenock | Garvel point | 8 ,, | Light for four seconds, with two short eclipses in the next four seconds. |
| 361 | Troon Harbour | Inner end of pier | 1 minute. | Visible 40 seconds, eclipsed 20 seconds. |
| 373 | Galloway Mull | S.E. extreme | ¾ ,, | ,, 30 ,, ,, 15 ,, |
| 418 | Ribble River | S.E. of Stanner point, N. side of entrance | 4 ,, | ,, 3½ minutes, ,, ½ minute. |
| 442 | Lynus | On the point | 10 seconds. | ,, 8 seconds, ,, 2 seconds. |
| 454 | St. Tudwall | West Island | 10 ,, | ,, 8 ,, ,, 2 ,, |
| 494 | Bristol Channel Burnham | E. side of entrance of Parret River | 4 minutes. | White with red sectors, visible 3½ minutes, eclipsed ½ minute. |
| 512 | Cork Harbour | Roche point, E. side of entrance | 20 seconds. | ,, 15 seconds, ,, 5 seconds. |
| 521 | Mine Head | S. side of head | 1 minute. | ,, 50 ,, ,, 10 ,, |
| 536 | Wicklow | On the head | 13 seconds. | ,, 10 ,, ,, 3 ,, |
| 542A | North Bull, Dublin Bay | End of North Bull wall | 14 ,, | ,, 10 ,, ,, 4 ,, |
| 555 | Dundrum Bay | St. John's point | 1 minute. | ,, 45 ,, ,, 15 ,, |
| 562 | Belfast Bay | On elbow of Hollywood bank in 8 feet water | 12 seconds. | Eight seconds of light, followed by two short and one longer eclipse. |
| 566 | Rathlin | Altacarry head, N.E. point of Island | 1 minute. | White with red sector, visible 50 seconds, eclipsed 10 seconds. |
| 600 | Loop Head | 500 yards, E. by S., from extremity of head | 24 seconds. | ,, 20 ,, ,, 4 ,, |

## III.—Occulting or Eclipsing Lights.

The 21 eclipsing lights at present existing in the British Islands are described in the preceding Table (see page 13), extracted from the Admiralty List of Lights for 1881.*

To these is to be added the Cardross light on the Clyde, at present a red light, but which, before the end of next month, is to be converted into a white eclipsing light of the same character as the Craigmore light in Rothesay Bay, long-short-long-short. It was judged by the Trustees of the Clyde Navigation, under whose charge this light is, that the long-short-long-short would be thoroughly free from liability to be mistaken for the occulting light (short-short) off Garvel Point, three miles from it, and would, in the circumstances, give it a more telling characteristic quality than a single eclipse in the period, or than any group of three eclipses.

It will be seen, from the preceding table of occulting lights that, with the exceptions of Hollywood Bank, Craigmore, Garvel Point, Chapman, and Cardross, the distinction in each case is only a single eclipse in the period, and that, except in nine of them, the period is one minute or upwards, but in all, except five, the duration of the eclipse is less than half a minute. In all the more recent eclipsing lights the period is half a minute or less, and the duration of the eclipse is at most five seconds. The tendency, undoubtedly, is to quicken the action still further, following the example of the old Point Lynus light, with its eight seconds of visibility and two seconds of eclipse.

The necessity for a very short period is not so urgent in the case of eclipsing lights as it is in the case of flashing lights. A long period in the case of a flashing light means a long period of darkness, throughout which the light is lost sight of. The inconvenience of a long period in an eclipsing light is merely the length of time during which the sailor

* Since the publication of this List, it has been announced that the Chapman Light, on the Thames, is to be "*occulting,* twice in quick succession *every half-minute,*" which is the same as Garvel Point, on the Clyde, except that the period is *half-a-minute,* instead of the *eight seconds'* period of Garvel Point.

may have to wait to know which light it is; he never loses sight of the light except for the two or three seconds' duration of one of the eclipses. But quickness of each group is just as important to allow ready and sure identification of its character as is the quickness of a group of flashes in the group-flashing lights, of which I have already spoken.

The important question is now be met—How may eclipses be best arranged to give the requisite number of characteristic distinctions, for the large number of fixed lights on our coasts which need distinction, with as little as may be of interference with the valuable quality of fixity? The answer, I believe, is by groups of eclipses described as follows:—First —one, two, three, or four very short eclipses, say of not more than one second each, separated by equal intervals of light in the group, and the groups of eclipses following one another after intervals of not less than eight seconds of undisturbed bright light; next groups of two or three short and long eclipses, the short eclipse one second, the long eclipse three seconds, the interval of light between the eclipses of a group one second, and the interval of undisturbed light between the groups of eclipses not less than eight seconds. I fixed upon the time one second, because, after many trials of mechanisms to produce the eclipses, I found that I could produce all the groups of eclipses at the rate corresponding to one second for the short eclipse by a simple and inexpensive machine applicable to any lighthouse, large or small, and of any variety of optical arrangement, whether merely with condensation to the horizon, or with the additional appliances required to condense into a particular azimuth.

A machine fulfilling these conditions is now at work in the college tower of the University of Glasgow, performing the short-long-short of the following table for four hours every evening. It has been doing this for a month, and shows no signs of wear. Indeed, there is no part of the machine which is liable to wear in the course of years' regular service in a lighthouse. I refer to this machine at present, because it has been supposed that the plan of mechanism used in the Hollywood Bank light, and Garvel Point, Craigmore, and

Cardross lights—that is, a mechanism producing eclipses by revolving screens, and therefore applicable only to lights without azimuthal condensation—is the only mechanism which can practically produce the groups of eclipses at the speed necessary to carry out this method of giving characteristic qualities to fixed lights.

My proposal for giving character to fixed lights is at present definitely limited to the ten varieties shown in the following table—the short eclipse being one second, the long three seconds, in every case, except the one-short and the long-short-long-short. In these the short eclipse is a half-second; and the long eclipse is three half-seconds.

| Number of eclipses in each group. | Description of the eclipse. | Time from beginning to end of each group of eclipses. | Period of time from beginning of one group to beginning of the next. |
|---|---|---|---|
| One...... | Long.................... | 3 seconds | 12 seconds |
| One...... | Short.................... | ½ second | 10 „ |
| Two...... | Short-short.............. | 3 seconds | 12 „ |
| Two...... | Short-long............... | 5 „ | 15 „ |
| Two..... | Long-short............ .. | 5 „ | 15 „ |
| Three... | Short-short-short........ | 5 „ | 15 „ |
| Three... | Short-short-long......... | 7 „ | 20 „ |
| Three... | Short-long-short......... | 7 „ | 20 „ |
| Three... | Long-short-short......... | 7 „ | 20 „ |
| Four*... | Long-short-long-short... | 5½ „ | 15 „ |

It is to be remarked that the times stated in the third and fourth columns need not be known or noted to let the light be recognised. The description in the second column, "short-short," for instance—or "short-long-short"—or "one long"—or "one short"—as the case may be, suffices, and is intelligible to every one, learned or unlearned, and lets the light be recognised with the greatest ease. As to the distinction between "long" and "short," the contrast between the two, following one of them instantly after the other, is unmistakable. The only cases of the preceding table in which there is not this contrast to show the distinction are the first and second; but the half-second eclipse of case 2 cannot in practice be ever mistaken for the three-seconds eclipse of case 1, which is six times as long.

* This characteristic is very easily read, and may be used with advantage in cases in which there is no practical difficulty in obtaining speeds corresponding to the times half-second and three half-seconds for the short and long eclipses.

It is obvious this plan may be understood immediately by any person learned or unlearned, reading the description, or being told it by word of mouth, and that no knowledge of the Morse letters corresponding to the several groups of eclipses is needed. Indeed, if Mr. Preece and others had not let out the secret, I might have brought forward this proposal without any acknowledgment of indebtedness to Morse or to Captain Colomb, had I been disposed to omit to give credit where credit is due for very brilliant and valuable inventions, and had I thought only of the very best way of putting forward my little suggestion in the manner most likely to promote its early adoption by the lighthouse authorities.

I have only to add, in conclusion, that the highly important suggestion of Sir Richard Collinson, to use a high and a low note in direct contrast, to give characteristic sounds for lighthouses, may be worked out systematically in a very convenient manner by using the combinations of the preceding table; with a high note instead of the short eclipse, and a low note instead of the long eclipse; the low note of the same duration as the high note; the interval between the notes of each group about the same as the time of each blast; and the interval of silence between the group of blasts much longer than the whole time of each group. When the fog-syren is used there is no difficulty in making the blasts as short as we please, and they certainly ought not to be longer than a half-second or three-quarters of a second. Quickness is here, as in many other nautical matters, of vital importance. Let any one try for himself, sounding a high and a low note in rapid succession, or two high notes and a low, or any other of the combinations of the preceding table, and he cannot fail to be convinced there is in each case a characteristic sound, which needs no musical ear for its appreciation, and which cannot be misunderstood by any one who has heard it, or has read it as the description of the sound of such and such a lighthouse, or has been told of it by word of mouth. The distinction between long and short blasts, as Mr. Price Edwards pointed out in his communication

to the Society of Arts already referred to, has not proved satisfactory in experience; and I believe this will generally be admitted to be the case by those who have experience of the working of the Morse system of long and short blasts of the steam-whistle or syren at sea. There is an uncertainty as to the instant when the sound ceases, prolonged as it often is by echoes, and in the case of the steam-whistle, an uncertainty also as to when it begins, which is very distressing to any one trying to understand Morse-signals by long and short sounds. But corresponding signals by very short high and low notes following one another very quickly, with ample times of silence between the groups of sounds, are exceedingly clear, and may easily be distinguished, even when the sounds are barely audible.

# PROGRESS IN YACHTING AND YACHT-BUILDING.

By G. L. WATSON, Naval Architect.

*ON FRIDAY, 18th FEBRUARY, 1881.*

When I was asked by our committee to give one of the usual weekly lectures, I consented to do so with some diffidence, doubting my ability to make a technical subject sufficiently interesting to a general audience, such as is now present. So soon, however, as I determined to speak to you about Yachts and Yachting, many of my difficulties vanished, as that is a branch of naval architecture in which the public is much interested, and it happens to be the one with which I am best acquainted.

Yacht-building may be called the poetry of shipbuilding, and it would be surprising indeed were Glasgow folks indifferent to anything relating to ships or shipping. Besides the fact of those glorious traditions of the early days of steam navigation centering in Glasgow and the Clyde, the great bulk of our population have to do with ships more or less directly. The enormous sum of six millions sterling was spent last year in ships and their engines in the Clyde district alone—that is, a sum passed into the pockets of our people, through our shipbuilders, which would give every man, woman, and child in the city £12 each. In this calculation I admit I have not deducted the builders' profit; but, as I never met any one of them who had made money on a ship, this won't alter the argument.

But when I propose to engage your attention to-night on the subject of yacht-building, it is not as a dependent, albeit beautiful sister of the art of shipbuilding; yachting has become one of our great national amusements. Sporting periodicals devote a large portion of their space to recording the movements of our pleasure fleet—our daily papers have their regular yachting column—at least one magazine treats of nothing else; while even the "Superfine Review" condescends at times to enliven its pages, by an article displaying more or less information on yachting subjects. It is not very many years ago when the sport was in a different, but no less healthy state. There were but half-a-dozen yacht clubs in the kingdom. Yachtsmen were looked on as a species of amiable lunatic, and if the poor fellows wanted to find out what their favourite craft were doing, they had to wade through *Bell's Life* to find a three-line report, squeezed into a corner by a dozen columns of close print telling them how the "Tudburry Pet" did, or did not, thrash the "Millwall Slasher."

But it is quite time we were taking things in their order, as only epic poets are allowed to commence their story in the middle.

I had every intention, then, of claiming the ark as a yacht, but at the opening of this Exhibition Mr. John Burns put her down as a cattle ship, and I could have nothing to do with her after that. The M'Leans, however, had a boat of their own at the flood, and as this craft was certainly not engaged in trade, she comes under the designation "yacht," and, as the first of her class, gives to us Scotchmen the credit of originating this particular kind of vessel. Whether this story is true or not I cannot say—it is probably as authentic as most family traditions; but it is certain that at a very early period of the world's history, boats were invented, and I take it, men first ventured on the face of the water for pleasure, before they did so for profit or war. The invention of sailing—at least sailing before the wind—follows as a matter of course. You have all, doubtless, heard the story of how the fisher girl saved her sweet-heart's life, and discovered balloon canvas. I find that Æneas had sails in his ships; more than that, he

anticipated our yachtbuilders by some thirty centuries, and over-sparred his boats too, as Virgil, in a magnificent description of a galley race, says—

> "Cloanthus, better manned, pursued him fast,
> But his *o'er-masted* galley checked his haste."

I am tempted to quote just a little bit of this, as, although it is written about a rowing race, it describes in its every feature just such a luffing match as one may see at any yacht race, down to such minute details as the swearing of the captain and throwing the pilot overboard. This latter incident has actually occurred. I am bound to say, however, the pleasantry was carried out by some of the enthusiastic "bhoys" on the other side of the Channel.

After a description of the prizes, which would make a modern pot-hunter's mouth water, Virgil goes on to say:—

> "Proud Gyas charged his pilot, 'Stand,
> More close to shore, and skim along the land;
> Let others bear to sea.' Menœtes heard,
> But secret shelves too cautiously he feared,
> And fearing sought the deep; and still aloof he steered.
> With louder cries the captain called again—
> 'Bear to the rocky shore and shun the main!'
> He spoke, and speaking, at the stern he saw
> The bold Cloanthus near the shelvings draw.
> Betwixt the mark and him the Scylla stood,
> And in a closer compass ploughed the flood.
> He passed the mark, and, wheeling, got before.
> Gyas blasphemed the gods, devoutly swore,
> Cried out for anger, and his hair he tore.
> Mindless of others' lives (so high was grown
> His rising rage) and careless of his own,
> The trembling dotard to the deck he drew,
> And hoisted up and overboard he threw.
> This done, he seized the helm: his fellows cheered,
> Turned short upon their shelves, and madly steered.

You see human nature was pretty much the same then as now, and this being so, I think it safe to assume that, with galley racing, chariot racing, and foot racing before them, and sailing an accomplished fact, men would be having a try at racing under sail; indeed, Captain Cloanthus' "O'er-masted

galley" points to this. To pass over a couple of thousand years or so, in which the world went round, but yachting stood still, the first mention I can find of yachts, as we now understand the term, is in Charles the Second's time, where the "King's yacht" is spoken of; but she was evidently just a vessel set aside for the King travelling by, and it is not till 1690 that there is mention of yachting as a sport. There, in an account of one of those numberless Jacobite plots, Macaulay describes what must have been a terribly exciting race. He says:—"At dead of night, the last night of the year 1690, Preston, Ashton, and Elliot went on board of their smack near the Tower." But Caermarthen had got wind of the plot, and "took his measures with his usual energy and dexterity; his eldest son, the Earl of Danby, a bold, volatile, and somewhat eccentric young man, was fond of the sea, lived much among sailors, and was the proprietor of a small yacht of marvellous speed. This vessel, well manned, was placed under the command of a trusty officer named Billop, and was sent down the river as if for the purpose of pressing mariners. The conspirators meanwhile had passed Gravesend without being challenged, their spirits rose, their appetite became keen; they unpacked a hamper well stored with roast beef, mince pies, and bottles of wine, and were sitting down to their Christmas cheer when the alarm was given that a vessel from Tilbury was flying through the water after them. They had scarcely time to hide themselves in a dark hole among the gravel which formed the ballast of the smack, when the chase was over, and Billop, at the head of an armed party came on board." Elliot, we are told, stormed and swore at being caught. I am glad to say manners are infinitely better now-a-days, and that "language" is never indulged in, even when being passed by another boat.

Eight years later, Peter the Great visited England, and the same authority says that his favourite amusement was navigating a yacht up and down the river. It may possibly have been the same wonderfully fast little vessel, as "the only Englishman of rank in whose society the Czar took much pleasure was the eccentric Caermarthen." It seems, therefore,

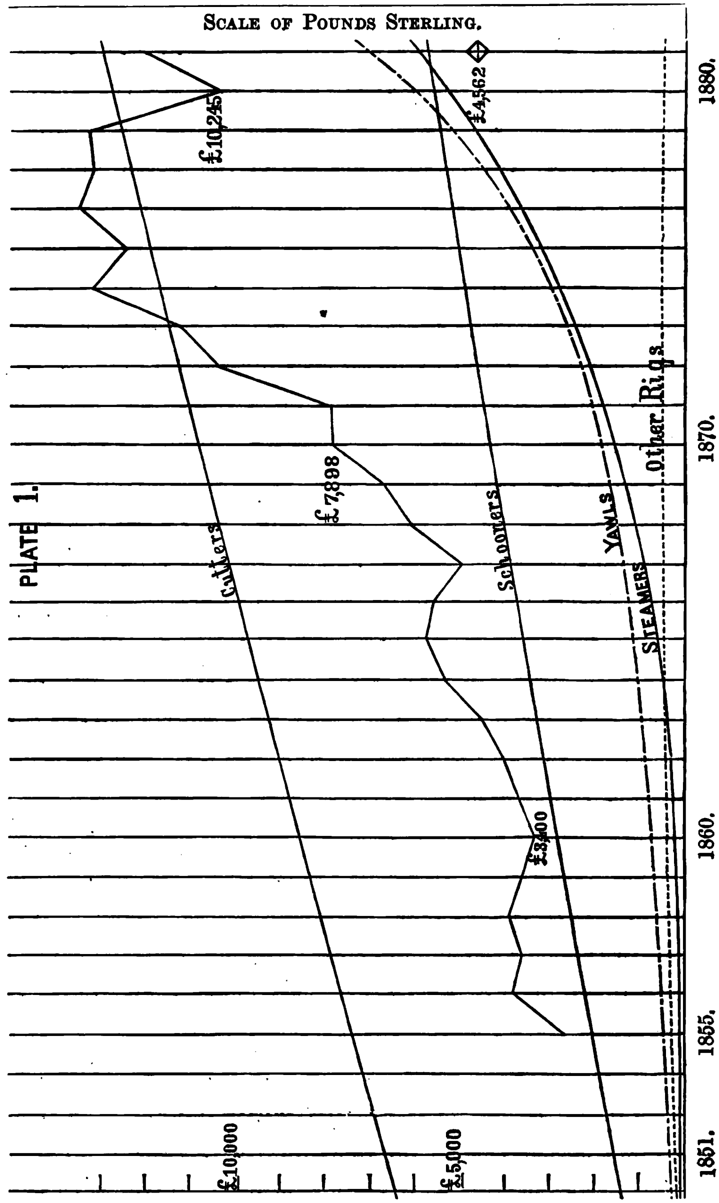
but natural that his successor, the present Czar, should be the owner of the most remarkable structure which has floated on the face of the waters since Noah's day. I can almost fancy that, if anything would tempt the shade of the "royal shipwright" to "revisit the glimpses of the moon," it would be the hope of seeing the "Livadia."

During the eighteenth century yachting was indulged in only by a few noblemen, and these seem to have been looked on as eccentrics. It was not till the beginning of this century that yachting became a recognised sport, but even at that date there were probably not above fifty yachts afloat. In 1815 (Waterloo year) the Royal Yacht Squadron was established, but this was not the first yacht club, as nearly a century before that, the Cork Harbour Water Club, now the Royal Cork Yacht Club, was founded. In 1824 our own Royal Northern Yacht Club commenced its career, the head quarters being in Belfast Loch. The year after, the Club was joined by a number of Clyde yachtsmen, and presently became an entirely Scotch club. By 1852, the year after America's victory, there were 17 royal yacht clubs, besides several smaller clubs which had not been granted the warrant. To-day there are 31 royal yacht clubs, and I should say at least double that number which have to content themselves with flying the red ensign.

A word as to the tonnage owned by these clubs. As I said, in 1800 there may have been about 50 yachts afloat, in 1850 this fleet had increased to 503, in 1864 to 895, in 1878 to 1883, and in this year of grace there are fully 2000 yachts owned in this country, having a gross tonnage of 100,000 tons.

The diagram (Plate I.) shows this increase and also the increase of each rig.

I would have you notice especially the steamer and yawl lines, showing the enormous increase in this particular kind of yachting. Curiously enough, the average tonnage per yacht has varied very little, remaining at 44 for 1850 and 1864. 1878, however, shows a slight increase, the size (47 tons) having been, no doubt, run up by the building of so many big steam yachts.




I said that the nation owned some 100,000 tons of yacht property (it would make a very respectable navy for many a

State), and if the first cost of these be taken at £40 per ton, which is a pretty fair average, the money invested in this way is seen to be considerable, amounting, as it does, to £4,000,000.

We may allow that three-fourths of this fleet is put in commission yearly, and this means that over three-quarters of a million is spent annually in its maintenance, while six thousand of the smartest seamen in the country find employment in manning it. With these facts before you, and with the knowledge that a very large sum is given annually by the State in prizes for horse racing, you will conclude that yacht racing is also subsidized; and so it is. It was evident to our rulers that the pleasure navy employed a reserve of men which could be drafted into the Royal Navy in case of war, that the modelling of sailing yachts had exercised no small influence on the shape of larger vessels, and that our steam yachts could be converted into despatch boats, torpedo boats and the like, at a few days' notice. For these reasons it has been deemed expedient to foster the sport by an annual grant to the yacht racing public of TWO HUNDRED GUINEAS It is true another Queen's cup is given, but this goes to the Royal Squadron, and the members of that august body are much too exclusive to jostle with outsiders for the trophy presented by our gracious Sovereign. They therefore have an annual race for it among themselves, in which, I was told by an irreverent, nay, impious Radical, the boats not unfrequently came in, in the order of rank of their noble owners.

Happily yachtsmen don't need State aid, and themselves subscribe about £12,000 to be run for yearly. The graphic curve (Plate I.) shows the amounts won by racing yachts from the year 1855 till now. It shows a pretty regular increase, and, although not absolutely fair, "we may conclude," to quote from some of my scientific friends, when speaking of their speed curves, "that those trifling irregularities which do occur are due to inaccurate observation."

The mark on the 1880 line shows the amount won last year by Clyde-built yachts; and I may remark in passing that, if we except the schooners and 40 and 20 ton cutters,

our Clyde-built or Clyde-designed boats are at the head of every other class, both in number of prizes and amount of money won, from the big "Latona" down to the little 3-ton "Senta."

While the taste for yachting has developed enormously in this country, our neighbours have also shown an aptitude for the sport. As a matter of course, our cousins in America built yachts, and even had the audacity to beat our home productions. At the close of the war in 1865 they had ten yacht clubs, with 800 members (not very many more, you see, that our own Royal Clyde Club), but now they have 100 clubs, with an aggregate membership of 7,500, while their yachts, if perhaps smaller than ours, are almost as numerous.

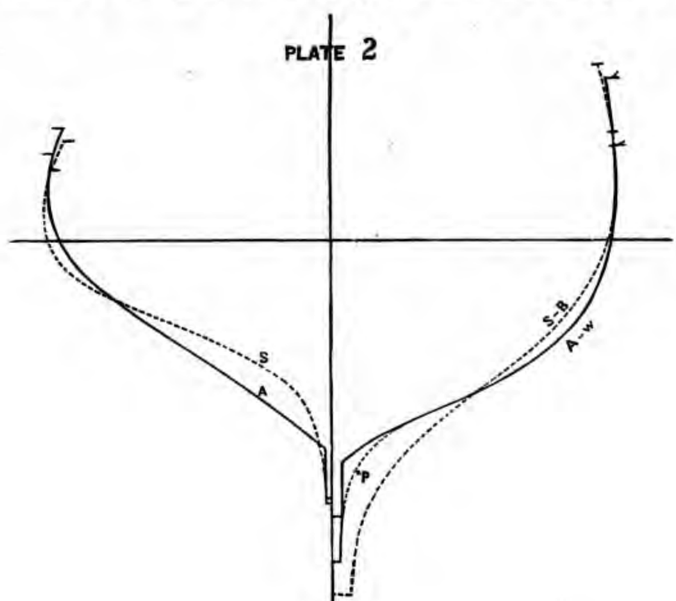
In Australia, New Zealand, Canada, India, wherever our tongue is spoken, there yachting is a favourite sport. The Dutch have long sailed their "yots;" indeed, the word "yacht" is taken from them. Frenchmen, year after year, are buying boats from this country. Italian and Portuguese yachts are seen in the Mediterranean; while Russian, Danish, and Swedish pleasure vessels navigate the stormier waters of the North Sea.

It is now time I said something on a more congenial subject, namely, the progress which has been made in yacht-building, and under this head I will have a word to say on the ballasting, sails, and equipment, as well as the actual hull. We need not go back, I think, further than the beginning of this century, as the yachts built prior to that date could not very well have been bluffer or more unsightly than they. They seem to have been about three beams in length, and had bows like a serving-mallet, while any whitling away of the model was off the after-end. But even at that early date, they were not altogether flat in the bottom, and on Sir William Symonds becoming Surveyor of the Navy, in 1832, yachts were made still sharper in the floor. Sir William seems to have influenced the form of yachts almost as much as the model of vessels of the Royal Navy; indeed, it was as the designer of a wonderfully fast yacht, the "Nancy Dawson," that he first came before the public as a naval architect, and

on the head of that success was asked to design a corvette—she also turning out very fast. I fear there is little chance of the present Government following up such an admirable precedent, and that we yacht-builders won't be asked for our opinion on the next batch of armour-clads.

Very nearly sixty years ago the old "Arrow" was built by Mr. Weld, who was a most enthusiastic yachtsman and yacht-designer. In those days the best yachts seem to have been built by amateurs—the "Menai," 163 tons, apparently the best boat in a breeze, being designed by Mr. T. Assheton Smith. This "Menai" anticipated Mr. Scott-Russell's theory by some years, as she is said to have been the first vessel built with a long and hollow bow. The old "Arrow," which seems to have been neither better or worse than the run of the Solent yachts, and may be taken as a representative boat of her time, was a barrel-bottomed craft, with the usual cod head and mackerel tail. Her length was 61 ft. 9 ins. by 18 ft. 5 ins. by 8 ft. 8 ins. depth of hold—about $3\frac{1}{3}$ beams in length. Her midship section is shown in Plate 2, by the full line on right hand

PLATE 2



90-ton "Vanduara." Mr. Smith got another boat from the same firm in 1826; and the first of the famous "Falcons" was built in 1827, while a year later the "Sylph" was launched for Mr. Crooks of Levan House. These two, with the famous "Clarence," "Rattlesnake," "Nancy," and "Gleam," helped to form the fleet of our Royal Northern Yacht Club. They did a lot of racing in the Firth and neighbourhood, and established that taste for yachting among us Clyde men which has been on the increase from that day to this.

The owners of these old craft were perhaps more genuine yachtsmen than our present generation. They were thorough sailors, with a love for the salt water and for their boats, which I fear we don't understand now-a-days. The modern yacht owner regards his vessel in the same light as his carriage, and would as soon think of having a sentimental attachment for the one as the other. I remember reading an account which struck me very much at the time, of a famous yachtsman, and how, as he lay on what proved to be his death-bed, a telegram was handed in, telling how his boat, which he had built years before, had won, against some of our best modern yachts. The old man, enfeebled by age and sickness, burst into happy tears at the news.

We employ all our science now-a-days in the building of the yachts, but our fathers got as much of it as they wanted in sailing theirs. The fleet when cruising formed port and starboard division, and were directed by signal from the commodore, as to change of position or other evolutions. We know nothing of that now, but, on the other hand, can tell a meta-centre from a marline-spike—a certain section of our yachtsmen absolutely revelling in wave curves, centres of effort, surface friction, and the like. I am bound to say it is in the South we hear most of this scientific jargon—we Clyde men, as a rule, contenting ourselves with kindly, simple bounce about jib-topsails and spinnakers.

But to get back to the Solent.

In 1844 Mr. Thomas Chamberlain saw the hull of the old "Arrow" as she lay in the Itchin river, and, fancying the form of her midship section, bought her from the dealer to whom

she belonged for some £116, which was not a big price for a boat, but was a good deal for a midship frame. New ends were built on this, and in 1846 this old midship frame began another career. But the bow does not seem to have been very much better than the old ship's, although the after-body was long and fair—very much the same as it is to-day.

Through the courtesy of Messrs. Camper & Nicholson, the well-known yacht-builders of Gosport, I am enabled to show you what form these old boats were. These are the models of two yachts built by that firm. The one, of the cutter "Intrepid," 60 tons, built in 1842 for the late Duke of Beaufort; and the other, of the schooner "Bianca," built in 1847 for Lord Clarence Paget. The cutter was not raced, but she was considered a smart and able craft, and that if she had been fitted out for racing she would have distinguished herself. The schooner was built for racing, and of the smallest tonnage that the Royal Yacht Squadron would admit; during the same year, or the following one, she won a 100 Guinea Queen's Cup in an open race round the Isle of Wight. You notice what very nice after ends both of these models have, while the bow would be thought full now-a-days for a coaster.

But the light was beginning to break, and men were unconsciously becoming prepared for the great change which was to revolutionize yacht-building. Already one or two patient observers of the phenomena connected with fluid resistance were confident that we were sailing our vessels the wrong end first. Long before this "Menai" had been built with a hollow bow, but her success had not been extraordinary, and it remained unnoticed.

In 1848 "Mosquito" came out, and made an immense sensation, but it was perhaps unfortunate that she was built of iron, as her speed seems to have been attributed to her material more than to her long and hollow bow. In 1850 Mr. William Simons, the well-known Renfrew shipbuilder, built in his yard a yacht which was far ahead of anything then afloat in the way of form. She was a long boat, being

a little under four beams; her dimensions Mr. Simons very kindly furnished me with. They are:—

| | | |
|---|---|---|
| Length on L.W.L., | - - - | 38 ft. 6 ins. |
| Do. over all, | - - - | 45 „ |
| Breadth, extreme, | - - - | 10 „ |
| Draft, do., | - - - | 7 „ 3 ins. |
| Do., forward, | - - - - | 4 „ |

I am sorry I cannot show you the model. I had the pleasure of seeing it the other day, and it is a very beautiful one; her bow was long and hollow, very like "America's," while the after-body was carried sweet and fair, into a long, deep-set counter, showing hardly any knuckle at the tuck. She was utterly unlike anything ever launched on the Clyde, and of course was condemned by every old salt who saw her. But "Tiara" came out, and did not sink in the first sea she got into, and was a wonderfully fast and successful boat in all weathers.

In 1851 there were articles in several of the sporting papers, and a sketch in the *Illustrated London News,* of a wonderful schooner which had been built in America, and it was rumoured that she was actually coming across to have a try with our English yachts. No one seemed to think very much of these rumours—the idea of America or other countries competing with us in shipbuilding, or, indeed, in anything else, was something too ridiculous. But in July, sure enough, the "America" had reached Havre, and was there shipping her spars for the races on the Solent; and *Bell's Life* had hardly time to record this before it was announced that the wonderful American clipper had arrived in our waters—indeed, was at anchor off Southampton. In a description given of her in that journal the reporter speaks of her long beautiful bow—the greatest breadth being about the main mast—her graceful head and sheer, the wonderful suit of sails, and, exhausting all epithets of admiration, he crowns his description by comparing her to a carrot divided longitudinally. On the day of her arrival she had a turn with one of our cutters, and *Bell's*

*Life* tells in what a wonderful way she lifted to windward of her. This trial completely scared our English yachtsmen, and the half-hour's lesson from the stranger was more laid to heart than the doctrine which the designers of "Menai," "Tiara," and "Mosquito" had been preaching for years. I need not recount "America's" victories—they were, indeed, somewhat inglorious, but that was not her fault, as she would have beaten our boats in any case, even had they not assisted matters by getting aground, colliding, breaking spars, &c.

I regret I have been unable to procure a model of "America" to show you, but her midship section is shown in Plate II. by the full line, marked A, on the left-hand side. You see she is a wholesome enough boat, very nearly as big-bodied as our own yachts built about the same time; and it is interesting to notice the effect of the different tonnage laws on the form of yachts, as exemplified by the sections of "Sea Belle" (dotted line, marked S — B), and "Sappho" (dotted line, marked S). For comparison's sake, the sections in the diagram are all brought to the same breadth, and starting from "America" you see how our tonnage rule has developed the narrow, deep, big-displacement vessel, while the American capacity rule has produced such a boat as "Sappho;" but "Sappho" is a big-displacement boat compared with some of the American yachts, and although these are undoubtedly fast in smooth water, they are a most unsafe type of vessel, as I have endeavoured to show graphically with this model. You see the English type of yacht rights itself, even when I knock her upside down, whereas the American one is at her position of maximum stability at 30 degrees, and possesses no stability whatever when she gets over to 80 degrees. Many good folks feel uncomfortable on board a yacht when she lies over, and, as an old lady friend once expressed it, "Dinna like thae yachts when they sail on their flet;" but those yachts "that sail on their flet" are the safest, and in the modern British type of yacht, one need never be uneasy, provided the water is kept out of her, and one keeps on board of her.

A great deal has been said about "America's" sails, and an attempt was made to let our builders down easy by blaming our sailmakers. It is true we were but feeling our way in this also, but the sails were at least as advanced as our hulls. The schooner was canvassed with cotton, the mainsail laced to the boom, and I have it from an eye-witness that the sails had been greatly ripped about and altered. Now, a laced sail is secured along three edges, and if one only takes a little trouble and patience, a tarpaulin can be made to stand so set. The Yankees also soaped their sails, and the cotton absorbing the moisture, it was no wonder the sails could be got like tinplate. Our sails then, as now, were laced only to the gaff and mast, which, if it can be got to sit, makes a better sail than the other. In no department of yacht-building has greater perfection been reached than with the sails, and whatever point we may have got to with the hulls of yachts, some of the mainsails turned out by Messrs. Lapthorn or by Mr. Charles Ratsey are simply perfection.

During the winter of 1851-2 the builders had their hands full, not with new work, but in lengthening boats by the bow, and Mr. Chamberlain lengthened his "Arrow" by putting 17 feet on the fore end. This greatly improved her, and though bothered occasionally by "Mosquito," she was queen of the Solent for some years. In 1857 Mr. Weld built the "Lulworth," a cutter of 80 tons, which was a very similar boat to the lengthened "Arrow," but smaller bodied. She was a bare match for "Arrow," and although she got some races from the older boat it must be remembered that "Lulworth" used weather ballast—a practice which Mr. Chamberlain never would allow.

In 1855 the "Glance," of 35 tons, was launched on the Itchen. She was a new type of vessel, and by a new man. Long, deep, with very fine ends, and a large midship area, she carried a lot of ballast, and carried it low down. She was faster on every point than the old shallow boats, and, able to sail round anything of her tonnage, not unfrequently saved her time on the larger yachts. Her builder, Dan Hatcher, gave us another wonder in 1857, and year by year produced such

vessels as "Vampire," "Vanessa," "Norman," "Maggie," "Freda," and many others scarcely less famous. It is but eight months ago since poor "King Dan" passed from among us into the territory of a greater and grimmer king.

But among the big boats "Arrow" still held the pride of place; and in 1861 the greatest compliment ever paid to a yacht-builder was paid to her owner in an appeal to withdraw her from competition. This Mr. Chamberlain refused to do, telling the owners to build one to beat her. It was the year 1865 before this was done, but it was then done thoroughly, and that by our beautiful "Fiona." This was a production of the present Mr. William Fife, and was a very big-displacement boat for those days; but with a great length for tonnage, her lines were singularly easy and shapely, her bow being especially beautiful. "Fiona" for a good many years got the lion's share of the prizes—indeed, her racing career finished, if it has finished, but a few years ago, and brings us quite into modern times, while her model has been adhered to pretty closely in Mr. Fife's recent successes, and I don't think I need recount these to a Glasgow audience. Are not "Neva" and "Cythera" as household words? How many did "Kilmeny" kill, or "Tortch" outshine? While a "Clio," a "Cyprus," and a "Neptune" attest, that the gift of knowing what the salt water likes has descended to a third generation. In 1867 Messrs. Steel launched "Oimara," one of the first composite yachts built, and to this day the grandest cutter afloat. She took some prizes from "Fiona," but she was so big (163 tons) that the little one generally saved her time, and had the prizes. In 1872, Ratsey of Cowes built "Khremhilda" for Count Batthyany. She had a wonderful season, and was rather too much for "Fiona;" but in 1874 "Neva" avenged her older sister. A year later saw "Vol-au-vent" afloat; and then came the beautiful "Formosa," which, I may tell you, is much more beautiful above water than below. None of these boats showed any striking novelties in form or construction, and the "Arrow," brought out every year with some improvement or another, still got a share of the prizes. I have often been asked about this wonderful vessel, and how a yacht sixty years

and can travel with the yachts of the present day. But, as we have seen, there is nothing that age about her except the midship frame, and that, by a wonderful piece of good fortune, happened to be an improvable shape. She has been remodelled time and again, always keeping her up with the latest ideas in yacht-building, and it is about as reasonable to talk of her being an old boat as for Paddy to boast that, "Bedad! he had wore the same pair of stockings for twenty years," when, on cross-examination, it turned out that "the wife" knitted new feet into them one year and new legs the next.

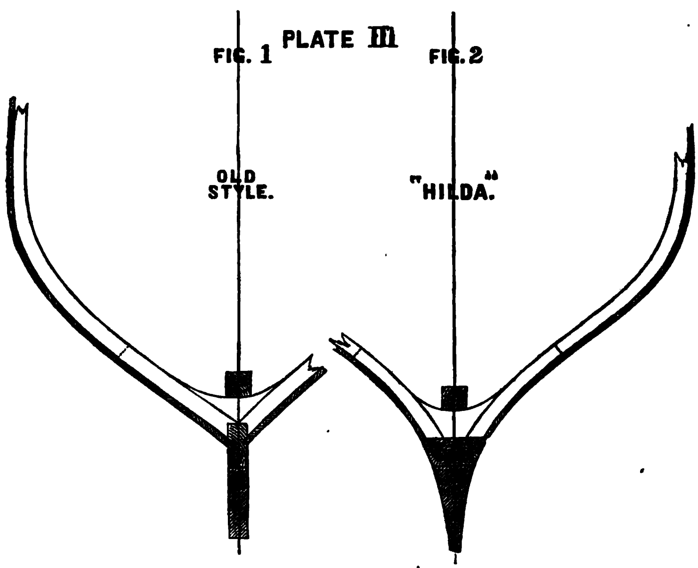
In a half-hour's lecture, such as this, one must of necessity miss many points which should have been touched upon. I have been unable even to mention many a famous boat and famous builder (when one passes over centuries by the score, he is apt, perhaps, to miss a little), but there is one detail I would like to speak of rather more fully. In talking of these old boats I endeavoured to explain the changes which have taken place in form as I went along. The introduction of the long bow, the gradual deepening and narrowing, and increase in displacement: yachts have, from being three times the length of their breadth, come to be $5\frac{1}{2}$ and 6 beams long: nay, one 10-tonner, just now building in England, is [illegible] feet long by 6 feet 6 inches beam, or nearly eight times the length of her breadth. These dimensions could never have been possible but for the change in the method of ballasting. At first yachts were ballasted with stones, or weights. You remember, in the account I read to you, that the conspirators on being overtaken tried to hide themselves in the gravel forming the ballast of the yacht, and such [illegible] was thought quite good enough for cruising boats, at [illegible] within the last twenty or twenty-five years. I notice in Vanderdecken's book, published so lately as 1873 (the papers, [illegible] first appeared in *Hunt's Magazine* some years prior to that), he speaks of sulphate of barytes and copper ore as [illegible] capital ballast, and in case we want to ballast a boat [illegible] gravel, tells us that a cubic foot of it weighs 120 lbs. I [illegible] piece of information won't be of much use to the

modern builder. Further on he says, "Instances occur, but rarely, of yachts being entirely ballasted with lead." All this was written, mind you, not much more than 12 or 15 years ago, and you will understand the enormous stride ballasting has made when I tell you that now there is hardly a racing yacht afloat, even the very largest of them, which is not entirely ballasted with lead. Many of our cruisers have lead, and even large auxiliary steam yachts, such as "Wanderer," "Sunbeam," or "Amy," go in for the precious metal. Now, all this means money, but money makes the mare go, and one must have money to make the yacht go too; for besides the direct outlay on lead, there are larger spars to make, and larger sails to put on them, more and bigger ropes, blocks, and gear, and the poor yacht-builder does not get more out of the job now, when racing boats cost say £50 per ton, than when they only cost £25.

Besides the change in the material, ballast has been differently applied. The first metal keel I can find any record of was put on the "Wave," a yacht built by Messrs. Steele, in 1834, for Mr. John Cross Buchanan. She was a great racer in her day, and took many prizes. Southern builders may have been putting lead outside before this, but, if so, I can find no record of it. For a long time builders were very timid about using external metal, and it is only within the last six or eight years that they have got more confidence, and season after season are putting a larger proportion outside. "Vanderdecken," in speaking of the "Kilmeny," says, "She had a keel of three tons, which, for a 30-ton vessel, seems a great deal; for a 25-ton vessel I should certainly put 2½ tons on the keel." This was plucky of "Vanderdecken," but now, some ten years later, we are putting more on our 3-tonners. To a Clyde man is due the credit of showing us how we were to do this, as, till Mr. John Inglis, junr., built the "Hilda," we were forming our boats in the old-fashioned way. Plate III., Fig. 1, shows the old style of keel; Fig. 2 shows the method adopted in "Hilda." Thus, the little 5-ton "Hilda" is, I take it, the grandmother of many of our racers. I, at any rate, am very pleased to acknowledge that it was

from her I took the idea of making what may be called a lead bottom to a boat, instead of a lead keel. I think we have come to the limit of outside lead now, at least in the smaller boats, as many of the 5's, 10's, and even 20-tonners have all but a mere percentage of their ballast

PLATE III




outside. Now, while this may be all very well with little boats, I much question whether a large vessel, if built of timber, can be made strong enough to withstand the enormous strain put on her by some 40 or 50 tons of lead lashing about, 12 feet below water, while the matter becomes doubly serious in the case of old boats which have never been intended to carry such weights there. It was for this, more than any other reason, that I earnestly advised the "Vanduara" being built of steel, and, I think, her owner's good fortune with her is but a fair reward for his pluck in trying such an experiment in a new material.

As prophecy seems now-a-days to be one of the branches of naval architecture, and we have been told by Sir E. J. Reed and others what kind of ships the next generation are to have,

I am anxious to keep abreast of the age, and herewith present you with the outline specification of a 10-tonner for the season 2000. You see I keep myself pretty safe, as but few of us will be alive to see her sail. The dimensions I won't venture on. Some yachting authorities assert that you have only to make the boats long enough and heavy enough to beat all existing racing craft, and it seems strange that, with this knowledge in their possession, they should not only have had sufficient self-denial to resist the building of certain successes, but have even gone the length of turning out duffers of normal dimensions. I think there is just a little more in it than that, and can't believe that a 10-tonner 80 feet long could ever be a success. We have not exhausted the possibilities of *form* yet, and really know very little more about it than Solomon did, when he confessed his inability to understand "the way of a ship in the sea," and when we do arrive at perfection in shape, we can set to then to look out for better material. The frames and beams, then, of my ideal ship shall be of aluminium, the plating below water of manganese bronze, and top-sides of aluminium, while I think it will be well to deck her too with that lightest of metals, as good yellow pine will soon be seen only in a museum. For ballast, of course, we should have nothing but platinum, unless the owner grudged the expense, when we might put the top tier of gold.

But by that date, I hope we won't care for sailing in such a sluggish element as the water. I firmly believe that some day the air will become as easily traversed as the earth or ocean. You all know these magnificent lines of our Laureate, in which surely the poet, as Carlyle said, becomes the prophet:—

"Men, my brothers, men, the workers, ever reaping something new;
That which they have done but earnest of the things that they shall do:
For I dipt into the future, far as human eye could see,
Saw the vision of the world, and all the wonders that would be:
Saw the heavens fill with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales:
Heard the heavens filled with shouting, and there rained a ghastly dew
From the nations' airy navies grappling in the central blue."

But I don't think we will ever do our carrying trade through the air, and will still send our bales, however costly, by rail or canal; while surely the world will some day learn the folly of war, and, with the "glorious art of murdering" one of our lost sciences, that happy era will commence of "Peace on earth, and good-will towards men."

# ON THE RISE AND PROGRESS OF STEAM NAVIGATION.

By W. J. MILLAR, C.E., Secretary Inst. Engineers and Shipbuilders in Scotland.

*ON FRIDAY, 25th FEBRUARY, 1881.*

In considering the Rise and Progress of Steam Navigation, we must necessarily go over a wide field, both historically and otherwise; and I propose, in the outset, to look briefly at the earlier stages of the steam-engine itself.

The earliest notice which we have of the use of steam is in the writings of Hero of Alexandria, who appears to have lived in the second century B.C., and, amongst other curious inventions which he describes as known in his time, he mentions a rotatory steam-engine.

For a long period we have little or no reference to the action of steam; and not until we come down to the seventeenth century do we find any reliable account of the use of steam as a motive power.

In 1663 it appears that the Marquis of Worcester, amongst other inventions, applied steam as a means of raising water; and George Macdonald, in his novel of "St. George and St. Michael," gives us pictures of the apparatus as fitted up at Raglan Castle.

In 1697, Savery invented an engine for pumping water out of mines. This was accomplished by the pressure and condensation of the steam combined with the pressure of the atmosphere.

It is to be noticed here that the steam was in immediate contact with the water; and it was not until 1690 that the piston and cylinder appear to have been used by Papin, the lower part of the cylinder serving as the boiler.

In 1705, Newcomen introduced the separate boiler, and, with the cylinder and piston, combined with the alternate pressure and condensation of the steam, gave us the atmospheric pumping engine. (See Fig. 1.)

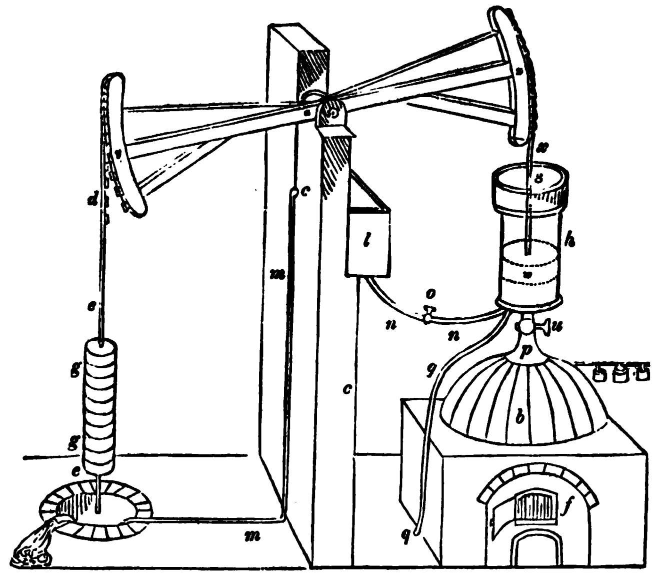


*Fig. 1.*

The valves were afterwards made to work automatically by Potter and others; and in 1770 Smeaton improved Newcomen's form of engine by increased pressure.

The memorable invention of the separate condenser was effected by James Watt in 1763 while experimenting with a model of a Newcomen engine in the old college of Glasgow. Some years after he patented the double-acting engine, in which the steam acts on each side of the piston alternately, and applied the principle of expansion of the steam in the cylinder. New life was, by these inventions, put into the whole, and the steam-engine became a really serviceable machine for commercial purposes.

The steam-engine, or fire-engine as it was then called, was, as yet, only used for pumping water, and had not been adapted to rotatory motion. This great improvement, viz.,

the addition of the crank, is also attributed to Watt; but Pickard appears to have patented the crank, connecting rod, and fly-wheel in 1780. Watt, however, in 1781, invented, amongst other rotative motions, the sun and planet wheels.

We have thus the use of steam by its momentum, as in the rotatory engine, and by pressure through the medium of fluid and solid pistons, as in Savery's and Newcomen's engines; also the communication of motion by rods or racks, and thereafter the change of the reciprocating to the rotatory motion.

Various improvements were from time to time effected, and, through the use of higher pressures, the expansive action of the steam became better utilized; and, indeed, the compound engine, which enables the expansion to be carried out so successfully in practice, appears to have been tried by Hornblower, Woolfe, and others as early as the beginning of the present century.

The propulsion of vessels by steam appears to have been from time to time proposed by the various inventors at work on the steam-engine; and amongst the earliest records of this we have trials by Savery and Papin with boats, in which the paddle-wheels or oar-like blades were turned by a water-wheel placed inside the boat and fed by a stream of water raised in the method adopted by Savery.

In 1736 and 1752, Hulls and Bernouilli proposed to propel boats by steam, the former by means of a paddle-wheel at the stern, and the latter by a kind of screw propeller. It is said that the Marquis de Jouffroy tried a steam vessel on the Rhone fitted with paddles and rackwork. The trial, which took place on 15th July, 1783, appears to have been very successful. The boat was 140 ft. long, with wheels of 14 ft. diameter.

During 1774 and 1790, Rumsey and Fitch, in America, were experimenting on the propulsion of boats by steam; and Rumsey, in 1786, propelled a boat by means of a jet of water from a pump worked by the engine.

Fitch, in 1785, appears to have tried a small steam-model, and proposed to use an endless chain and floats instead of

the paddles—a method tried at one time on the Clyde in the steamer "Queen of Beauty," afterwards named the "Merlin." Fitch afterwards, in 1790, worked a steamboat successfully on the Delaware.

Coming back to this side of the Atlantic, we find Patrick Miller of Dalswinton experimenting on paddle-wheel boats, and, combined with Taylor and Symington, tried a steamboat on Dalswinton Loch on 14th October, 1788. This boat was double, and measured 25 ft. in length by 7 ft. in breadth, and had two paddle-wheels placed one before the other. The engine had brass cylinders of 4 in. diameter, and was made by George Watt, in Edinburgh.

In 1789 the same inventors tried a larger vessel on the Forth and Clyde Canal, near Carron, a speed of about seven miles per hour being attained.

We now come to an important step in the history of steamboat propulsion. Hitherto the communication between the engine and propeller had been by rack-work, but now we have the newly-invented crank and connections introduced in the "Charlotte Dundas," designed by Symington in 1801

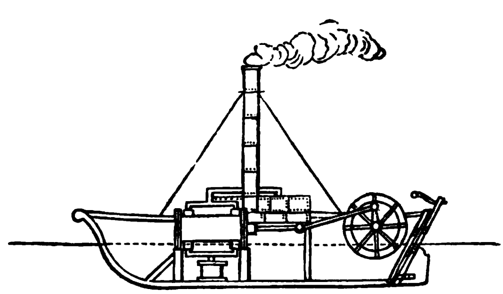


*Fig. 2.*

and tried on the Forth and Clyde Canal in March, 1802 when she towed two vessels to Port-Dundas at the rate of over 3 miles an hour against a head wind. Unfortunately, from fear of injury to the banks of the Canal, this successful experiment was stopped. This vessel was fitted with a horizontal engine acting directly on a paddle-wheel placed at

the stern through the medium of a connecting rod and crank. (See Fig. 2.)

In following this gradual development of steam propulsion we have again to cross the Atlantic, where we find Stevens and Fulton experimenting with steam-power—the former at first trying a rotatory engine. This being unsuccessful, he had recourse to the Watt engine, and managed to propel a boat 25 ft. long at 4 miles per hour.

It is to Fulton, however, that we must look for the really practical development of the steamboat in America. A native of that country, he visited England and France, and appears to have interested himself in marine experiments. When in England, in 1804, he ordered an engine from Boulton and Watt. This engine, which had a cylinder of 2 ft. diameter with 4-ft. stroke, was sent over to America, and Fulton fitted it into a vessel of about 130 ft. long by 18 ft. broad and 9 ft. deep. She was launched on the East River, New York, in 1807, and named the "Clermont." The engine had the cylinder placed vertically, and, by means of a bell-crank arrangement and spur-wheel gearing, the power was transmitted to the paddle-shaft. The "Clermont" made the trip to Albany, of 150 miles, in 32 hours.

We now return once more to the European side of the Atlantic, and find in our own neighbourhood efforts being put forth for the successful introduction of the steamboat.

Henry Bell, born near Linlithgow in 1767, came of a mechanical ancestry, and he himself studied both shipbuilding and engineering. In 1800 he proposed to the Admiralty to drive boats by steam, and again in 1803. As a body they had no faith, however, in the scheme. But it is recorded that Lord Nelson said—"My Lords and Gentlemen, if you do not adopt Mr. Bell's scheme other nations will, and in the end vex every vein of this empire. It will succeed, and you should encourage Mr. Bell."

It may be well to try and realise the existing conditions of that time. The great European war was still devastating the Continent, and Napoleon was on his campaign to Russia. The Battle of Waterloo had not been fought.

The inland traffic to and fro was by coach or canal boat, and the river and coasting traffic was by sailing vessels.

James Watt, as we have seen, had put new life into the steam-engine; but the snort of the iron horse of Stephenson had not yet awakened the sleepy echoes of the hills.

Glasgow had a population of about 115,000. The Clyde at that time was a winding, shallow stream, filled up largely with sandbanks, and it appears to have been no unusual occurrence then, and for some time afterwards, for the boats plying to Greenock and other ports, although only drawing at most 5 ft. of water, to get aground for an hour or so on a bank, the passengers meanwhile exercising themselves by running from side to side to get the keel loosened out of the sand.

In the year 1811 a terrific comet had shed its baleful glare for three months in the heavens, and it is to this uncanny visitor that we owe the name of our first river steamer, which, like the cometary body referred to, has been followed by a long and far extending tail, the limits of which we cannot define.

On our river, then, the "Comet" (see Fig. 3) was launched

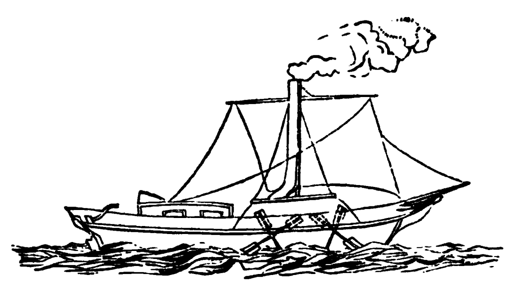


*Fig. 3.*

in 1812, from the shipbuilding yard of John Wood, at Port-Glasgow, and of whom Mr. Robert Duncan says—"He was the father of all that is best in the style of our ships, and truest in the practical application of science in the shipbuilding of Great Britain." * The boat was to the order of

* Presidential Address, Inst. Engineers and Shipbuilders in Scotland—Session 1872-73.

Henry Bell, and the engine was made by John Robertson, in Glasgow.

The visitors to this exhibition are fortunate in being able to see the original model and draft of this, the first European passenger steamboat, in the centre room below. And curious bluff-bowed crafts were some of these early boats, with the paddles close to the bows, and their long slender funnels, which soon began to emit those long and winding trails of smoke which, amongst many changes, still remain the most unimprovable part of the whole.

Fortunately, we are not wholly dependent on models and drawings of those early boats, as a specimen of the original type is yet with us in the "Industry" (see Fig. 4), which—

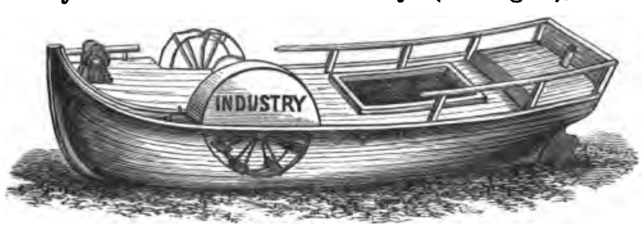



*Fig. 4.*

now nearly seventy years old—still lingers out, lying on the river sands at Bowling, where, like the canoes of the prehistoric Clyde navigators discovered there, she may in turn be silted up, and thus preserved to still later generations.

The "Comet" measured 42 ft. long, 11 ft. broad, and 5 ft. 6 in. deep; the engine was 3 horse-power, the cylinder being 11 in. in diameter, with a stroke of 16 in. By means of spur-wheel gearing the power was transmitted to two pairs of paddles. As this arrangement proved unsatisfactory, she was fitted with a single pair, and was lengthened to 60 ft.—the first engine being replaced by one of about 6 horse-power. The speed realised appears to have been about 6 miles per hour. Toothed wheels to connect the engine with the paddles appear to have been commonly adopted in the earlier boats. This will be noticed in Fig. 5, which is from a sketch recently made of the "Industry's" engine, which is also of the side-lever type.

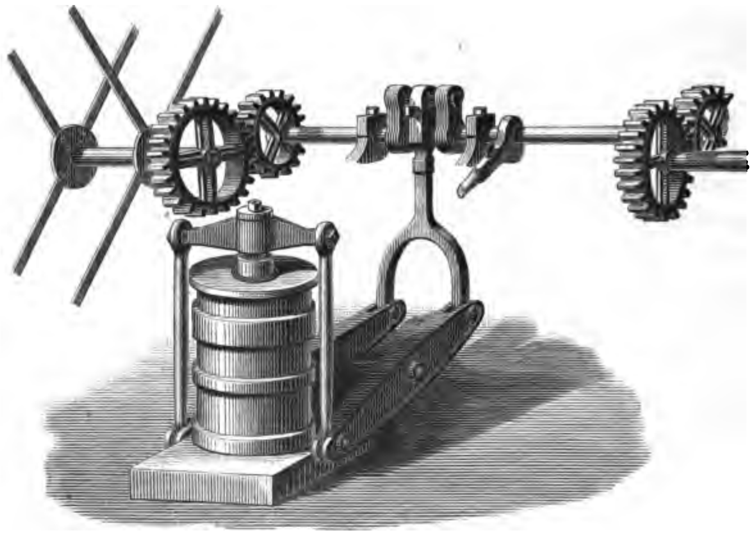


*Fig. 5.*

The following is the advertisement which was issued of the "Comet's" sailings:—

"The Steamboat "Comet," between Glasgow, Greenock, and Helensburgh, for passengers only.—The subscriber, having at much expense fitted up a handsome vessel to ply upon the river Clyde, from Glasgow and Greenock, to sail by the power of air, wind, and steam. He intends that the vessel shall leave the Broomielaw on Tuesdays, Thursdays, and Saturdays, about mid-day, or such an hour thereafter as may answer from the state of the tide; and to leave Greenock on Mondays, Wednesdays, and Fridays, in the morning, to suit the tide. The elegance, comfort, safety, and speed of this vessel require only to be seen to meet the approbation of the public; and the proprietor is determined to do everything in his power to merit general support. The terms are for the present fixed at 4s. for the best cabin, and 3s. for the second; but, beyond these rates, nothing is to be allowed to servants or any person employed about the vessel.

"HENRY BELL.

"HELENSBURGH, *5th August*, 1812."

The "Comet" was wrecked at Craignish in 1820.

It would be impossible in the time allotted to this lecture to name or describe in detail the various boats which followed the "Comet;" but it may be stated that the immediate followers of the "Comet" on the Clyde were the "Elizabeth," the "Clyde," and the "Glasgow"—all built in 1813; and in 1814, amongst others, we have the "Industry," already mentioned.

The "Elizabeth" measured about 58 ft. long, and appears to have attained a speed of 9 miles an hour; and I am told by a gentleman that he has gone to Greenock in the "Glasgow" in 2 hours and 10 minutes, the tide being with them. This boat was 72 ft. long, with an engine of 16 horse-power.

The following extract gives us some idea of the fittings of this early Clyde steamer:—"The 'Elizabeth' measures aloft fifty-eight feet; the best cabin is twenty-one feet long, eleven feet three at midships, and nine feet four inches aft, seated all round, and covered with handsome carpeting; a sofa, clothed with marone, is placed at one end of the cabin, and gives the whole a warm and cheerful appearance. There are twelve small windows, each finished with marone curtains, with tassels, fringes, and velvet cornices, ornamented with gilt ornaments, having altogether a very rich effect. Above the sofa there is a large mirror suspended, and at each side book-shelves are placed, containing a collection of the best authors, for the amusement and edification of those who may avail themselves of them during the passage—other amusements are likewise to be had on board."

In reading these early advertisements, we are forcibly struck with the changes which have come about through the lapse of years, especially when we look at our own river steamers, such as the "Columba;" and to those who have lately had the opportunity of visiting those two splendid vessels, the "Furnessia" and "Parisian," a comparison of the dimensions, power, and fittings would be still more striking; and to assist in this I may say that the "Comet," as originally built, would have just lain across the deck and within the breadth of the latter ocean steel liner, and that the first four

steamers already mentioned, if put end to end, would have only extended a short way beyond half of her length.

During the ten years following 1812, 48 steamers were added, one of which—the "Marjory"—was sent round to the Thames in 1815, and was the first steamboat there. She was 63 ft. long, and had a single side lever engine of 10 horse-power. In 1818 the "Rob Roy," a steamer of 90 tons and 30 horse-power, was the first to make the trip to Belfast; and the first to ply to Liverpool was the "Robert Bruce," of 150 tons and 60 horse-power, in 1819. Of another—the "Superb" —the *Steamboat Companion* for 1820 says:—"The 'Superb' is at this moment the finest, largest, and most powerful steam vessel in Britain. She registers 241 tons and is impelled by two very fine engines of 36 H.P. each, to which copper boilers are attached. The average duration of the passage from the Clyde to Liverpool does not exceed 30 hours. Fare, £2 15s." In 1821 another "Comet" was built for Henry Bell and others; and, by the way, this appears a favourite name, as I notice that one of the early steamers on the western rivers of America was named the "Comet," as was also the first steam vessel in the Royal Navy, built 1819.

The steam vessels by degrees were made larger and more powerful, and in 1821 the first iron steamer was built at Horsley, in England, and named the "Aaron Manby." The first iron steamer built on the Clyde was the "Aglaia," in 1827—this boat plied on Loch Eck; and the first to ply on the Clyde was the "Fairy Queen," in 1831. In 1839, the first iron vessel to ply to Liverpool was the "Royal Sovereign."

We now come to a notable period in the history of steam navigation, viz., the passage of the Atlantic.

As early as 1819, an American vessel—the "Savannah"—had crossed to Britain, partly sailing and partly steaming; and in 1833 the "Royal William" crossed from Quebec. In a recent notice of this vessel, *Engineering* says:—"The ship in question, named the 'Royal William,' was completed at Quebec in the year 1831. Two years later she sailed for London, making the trip in twenty-five days. Shortly afterwards the vessel was sold to the Spanish Government, and, being converted into a

man-of-war, was the first steamship ever used in that capacity. The price paid for her was 10,000 dols. In this connexion it will not be out of place to recall the fact that in the year 1819 there sailed from Savannah a full-rigged ship named after that city, and having an engine and paddle-wheels, which were used in calm weather, but taken in when the sea was rough." But it was reserved for this country to establish the commercial feasibility of such a traffic by the voyages of the "Sirius" and the "Great Western." The "Sirius" was built by Messrs. Menzies at Leith in 1837, the engines being made by Messrs. Wingate & Coy., Glasgow. She was 178 ft. long, and 450 tons, the engines were double and of the side lever type, and of 270 horse-power. It may be interesting to some to know that she was fitted with Hall's surface condenser, the tubes being arranged vertically. The "Sirius" started on 4th April, 1838, with nearly 100 passengers, and arrived in New York 17 days afterwards. The "Great Western" was built at Bristol by a Mr. Paterson, and engined by Maudslay of London. She was 212 ft. long, and 440 horse-power. This vessel sailed on the 7th April, 1838, and reached New York on the 23rd, after a 15 days' passage.

We have seen that the earlier attempts were due to individual ability and enterprise, and we come now to the period in which this bore fruit in the formation of the well-known companies whose fleets are spread far and wide, and encircle the globe itself.

The Great Western Steamship Company, who owned the "Great Western," afterwards added the "Great Britain"—a wonderful ship for her time—1843. She was built of iron, and fitted with a screw propeller, and measured 322 ft., with a breadth of 51 ft., and fitted with two geared engines of 500 H.P. each. Her main shaft was 28 in. diameter, with a 10-in. hole bored out, through which a stream of water played to keep it cool. The propeller was about 16 ft. diameter. She sailed from Liverpool to New York on 26th July, 1845, and arrived after a passage of nearly 15 days—average speed, $9\frac{1}{4}$ knots.

In 1840, the Cunard Company (then formed) placed the

"Britannia" on the passage, to be soon followed by others more powerful.

The "Britannia" was 207 ft. long, 34 ft. broad, and 22 ft. deep, with side lever engines of 403 H.P., the speed being about 8½ knots.

These fine paddle-boats culminated in the "Persia" (the first iron boat of the Company), and the "Scotia," the latter measuring 366 ft. in length; breadth, 47½ ft.; depth, 30½ ft.; tonnage, 4050; diameter of cylinder, 100 in.; stroke, 12 ft.; diameter of paddle, 40 ft.

The "China" appears to have been the first screw-steamer of the Cunard Company.

The Collins line of American steamers started in 1850, the "Arctic" being their first vessel, and, with continued additions, ran regularly for nearly 10 years.

The well-known Inman Company started in 1850, and it is of interest to note that their first steamer was the "City of Glasgow," 1600 tons, and 350 H.P., built of iron, on the Clyde, in 1850, and fitted with the screw propeller. She measured 227 ft. long by 32 ft. 7 in. broad and 24 ft. 7 in. deep, and was fitted with two geared beam engines, of 380 H.P.; the propeller was 14 ft. diameter.

The Allan and Anchor lines commenced in 1856; the Guion line in 1863; and the White Star in 1870.

The West India Mail Steam Packet Company commenced in 1841, with a fleet of large paddle steamers, amongst which was the "Amazon," burnt in 1852, when over 100 lives were lost.

The Pacific was now in turn to be traversed by the steamboat, and in 1840 the Pacific Steam Navigation Company was formed; and the progress of this Company was specially marked by the introduction of the compound engine in 1856.

In the Peninsular and Oriental Company we have an instance of large results from small beginnings. At first simply trading to Spain in 1830, in 10 years later it had extended to India, and established that well-known line of fine steam vessels.

It is interesting to note here that as early as 1825 a vessel named the "Enterprise," of 500 tons and 120 H.P., made the passage to India. The passage took about four months.

As we have already seen, the screw gradually took the place of the paddle; a vessel named the "Archimedes" being the first to be fitted, in 1839. The "Rattler" and "Dwarf" were the first screw steamers in the Royal Navy in 1843, and in 1858 the celebrated "Great Eastern," or "Leviathan," was launched, and fitted with both paddle and screw.

The dimensions of the "Great Eastern" are—length, 680 ft.; breadth, 83 ft.; depth, 58 ft.; with a tonnage of 22,500. She is fitted with four oscillating paddle cylinders, each 74 in. diameter, the stroke being 14 ft., and four screw cylinders, each 84 in. diameter, with a stroke of 4 ft. The diameter of paddles is 58 ft., and that of the screw 24 ft. Her first Atlantic voyage took place in June, 1860, occupying 11 days; and the average speed appears to have been 12⅓ knots. The "Great Eastern" is better known as a telegraph cable ship, however, than as a mercantile liner.

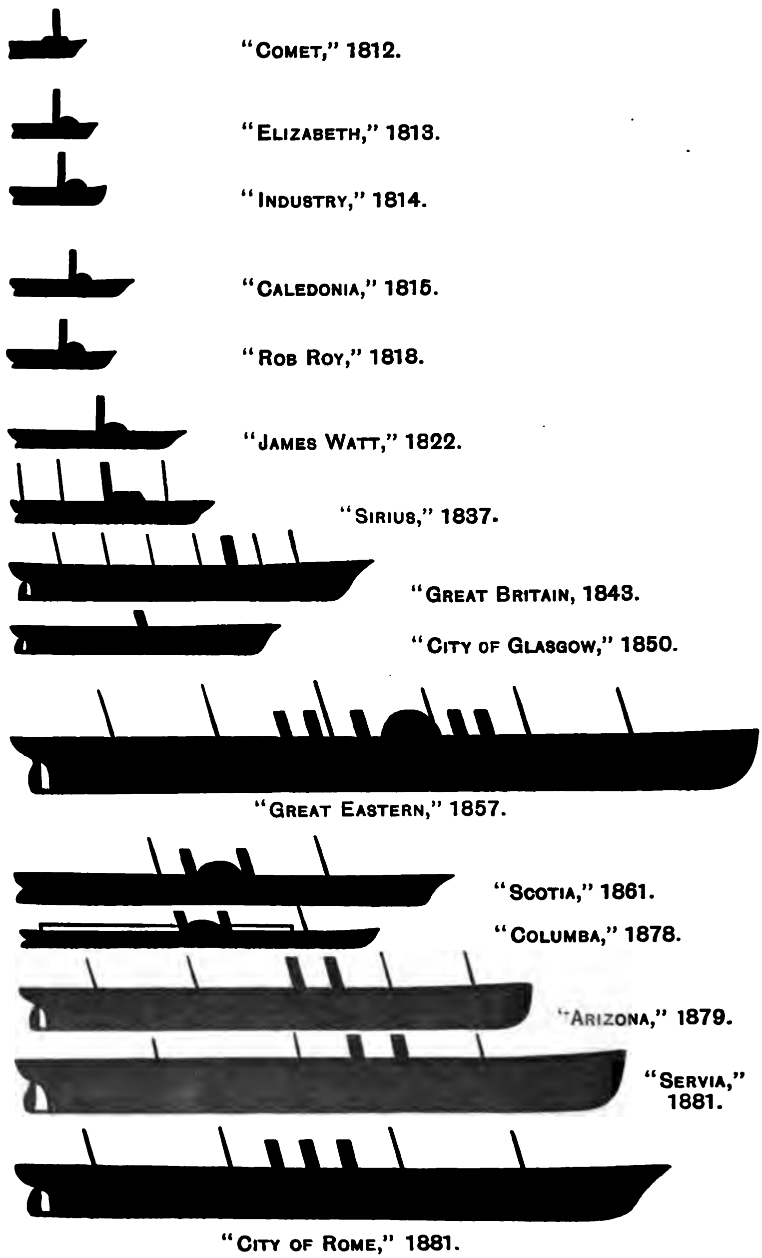
Many well-known names might be mentioned in connection with screw propulsion, both in this country and in America—such as Wilson and Kincaid in Scotland, Ericson, Smith, and Woodcroft in England, and Stevens and others in America—about the beginning of the present century down to 1836 or so.

Twin and triple screws have been tried, the "Livadia" being fitted with the latter.

Propulsion by jet was tried in H.M.S. "Waterwitch"—a turbine form of wheel turned by a steam-engine drawing in and forcing out water by passages at the sides of the ship.

In 1854 the compound engine was successfully introduced into marine practice by Messrs. Elder & Co., the "Brandon" being their first vessel. The "Constance" was the first vessel in the Royal Navy to be fitted with such engines, and by the same firm, in 1863.

To illustrate better the changes which have taken place in the sizes of our steamships, the annexed Figs. show a number of vessels, from the "Comet" downwards, all to the same scale


"Comet," 1812.
"Elizabeth," 1813.
"Industry," 1814.
"Caledonia," 1815.
"Rob Roy," 1818.
"James Watt," 1822.
"Sirius," 1837.
"Great Britain, 1843.
"City of Glasgow," 1850.
"Great Eastern," 1857.
"Scotia," 1861.
"Columba," 1878.
"Arizona," 1879.
"Servia," 1881.
"City of Rome," 1881.

We can only glance, in passing, at the forms of vessels. The earlier models, as may be seen, were bluff at the bow (see Fig. 4), and about five times the beam, changing gradually, until now we find proportions of ten times the beam.

The water lines were based on different curves—at first parabolic, then trochoidal (as in the wave line of Scott Russell), and now curves of the stream line form, as investigated by Professor Rankine, appear to be most successful.

We had double ships, starting with the early boat of Patrick Miller, the "Cigar" (1840), and the "Alliance" at a later date on our own river, with the channel steamers, "Castalia," and "Calais-Douvres." The "Cigar" was tried on the Clyde about 1840, and afterwards laid up at Glasgow Green. Curiously enough, in a spate during last winter a piece of this old craft was upturned from the sand in which it had been so long embedded. Another cigar-shaped vessel —the "Ross Winans"—was tried in 1864.

Circular-shaped ships for war purposes were proposed by the late John Elder in 1868, and the "Popoffkas" and "Livadia" models will be familiar to all those who have visited this exhibition.

Wood, by degrees, gave place to iron, and now the latter is being superseded by steel. And not only are the hulls being constructed of this stronger and more ductile metal, but also the boilers, with parts of the machinery.

The engine has passed through many forms, such as the side lever, steeple, oscillating, and diagonal direct-acting, and, in the latest form of the compound engine, the vertical direct-acting type; and here it may be stated that in the earlier screw steamers, cog wheels and chains, and even leather straps, were used to transmit the power from the engine to the propeller shaft.

The introduction of the surface condenser about 25 years ago enabled higher pressures to be maintained, and, instead of steam a few pounds above the atmosphere, as in the early steamers, we have now commonly 70 lbs., and in exceptional cases double and even higher multiples. The "Anthracite,"

fitted on the Perkin's system, having on her recent trip across the Atlantic carried about 500 lbs. pressure.

From the number of tubes in the surface condensers employed in the large steam vessels, the total length of a set for a single ship amounts to several miles.

The speeds and economy of fuel have likewise been largely improved of late years. The speed of the "Persia" in 1856 being about 13 knots, with a consumption of coal of about $3\frac{3}{4}$ lbs. per indicated horse-power, whilst the later boats of the Atlantic service attain a speed of from 15 to 16 knots per hour, with a consumption of coal of under 2 lbs. per indicated horse-power per hour. The difference in the time of the transit across the Atlantic may still better indicate this improvement in speed. The "Sirius" took 17 days in 1838. During the competition in 1851 between the Cunard and Collins' steamers, 11 to 12 days. In 1862, the "Scotia" made the passage in 9 days. And now the passage is made in little over 7 days. In reference to this, Mr. J. L. K. Jamieson says:—"Surely it is not too much to expect that in a few years hence it will be accomplished in six days, and that we shall have steam ships starting from each side of the Atlantic every morning, noon, and night, and arriving in the ports on the opposite shores with as much regularity as our present express railway trains are due at the termination of a journey of 400 or 500 miles."* In view of this, the first trip of the immense steamers now building for the Cunard and Inman Line, viz., the "Servia" and "City of Rome," will be watched with much interest, as these vessels are about 600 feet in length, and to be fitted with engines working up to 10,000 indicated horse-power.

In concluding this sketch, it may not be out of place to consider the origin of the mechanical power which has enabled such great undertakings to be carried out, and here we come to the coal.

Considered geologically, we might go still further, and affirm that, as this coal is but the carbonaceous matter of the

* Presidential Address, Inst. Engineers and Shipbuilders in Scotland—Session 1880-81.

vegetation of earlier epochs, it must owe its energy to the sun's heat and light, showered down upon the tropical-like swamps of that period.

Taking, however, the coal as we find it, we have a certain amount of hidden or *Potential* energy which, by combustion, may be made to appear in an active or *Kinetic* form, and known as heat.

We have thus a source of energy, and it only remains to see how this energy may be most efficiently employed in doing mechanical work. This may be done in at least two ways, viz.: by the hot-air engine, or by the steam-engine, in which the air in the one case, and the vapour called steam in the other, are the media employed.

The hot-air engines of Stirling, Ericsson, and others have a considerable efficiency, but are cumbrous in mechanism.

The steam-engine has, therefore, as yet been the more successful.

It can be shown that the combustion of 1 lb. of pure carbon develops 14,500 units of heat.

As in ordinary kinds of coal, there is a percentage of ash, &c., we only get by the combustion of our best coal about $\frac{8}{10}$ths of this, or say 12,000 units of heat; and since a unit of heat is equivalent to 772 foot-pounds of work, this lb. of coal will be good for about 9,000,000 foot-pounds of work.

Now, since heat may be in this way made to perform work, the efficiency of that engine will be highest which effects the greatest transformation.

Perhaps the simplest way to consider this question is to look at one of our most efficient marine engines of the present day, where we may say one indicated horse-power is equal to 2 lbs. of coal burned in the hour (it is sometimes less).

Now, 1 lb. of coal is equal to 9,000,000 foot-pounds of work, and 2 lbs., therefore, equal to 18,000,000 foot-pounds per hour, or say, equal to 9 horse-power (because 1 horse-power is equal in round numbers to 2,000,000 foot-pounds per hour, therefore $\frac{18000000}{2000000}$ equal to 9 horse-power), but our engine only gives us out 1 horse-power, therefore the efficiency is $\frac{1}{9}$th, $\frac{8}{9}$ths being lost.

A further loss takes place through the machinery and propeller.

It is not the province of this lecture to go into detail on this subject, but to those interested in the matter I may say that this loss takes place more or less as follows:—

| | | |
|---|---|---|
| Efficiency of furnace and boiler, | - | $\frac{6}{10}$ths. |
| Efficiency of the steam, | - | $\frac{2}{10}$ths. |
| Efficiency of machinery and propeller, | - | $\frac{5}{10}$ths. |

and by multiplying these together we have

$$\tfrac{6}{10} \times \tfrac{2}{10} \times \tfrac{5}{10} = \tfrac{60}{1000} = \text{about } \tfrac{1}{16}.$$

That still further improvements will yet be effected we need not doubt, and a higher efficiency obtained, as I think is obvious in looking at the ratios now given.

The steam-engine has had competitors in the air engine, and more recently in the gas engine, also, in electro-magnetic engines, and it seems to me quite probable that ere long we may hear of more powerful explosives than gas being used as a motive power.

In all this, however, we must remember that we are simply transforming energy in what we might call a latent form into the active form; and, therefore, those substances by means of which this can be most satisfactorily performed, will necessarily be selected to give form to the prime mover of the future.

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The Author is indebted to Messrs. Chas. Griffin & Co. for the use of Figs. 1, 2, and 3, and to already pnblished works for much of the contained historical matter.

# RESISTANCE AND SPEED OF SHIPS.

By FRANK P. PURVIS, Leven Ship-yard, Dumbarton.

*ON FRIDAY, 4th MARCH, 1881.*

In commencing my lecture upon the "Resistance and Speed of Ships," I will ask you to consider for a moment the most simple of all means by which it is possible to make a floating body move through the water. You have only to go to the banks of one of our canals in order to see it. It consists of tying one end of a rope to the body in the water and pulling at the other end. By this means force is communicated, along the rope, to the body, just enough force being required at every instant to drag the body against the opposing forces, one of which is the opposing force of the water. The first of these is the towing-force; the opposing force of the water is the resistance. If the speed does not vary, becoming neither greater nor less in successive instants, these two forces are equal to one another; if the speed is increased, a certain force extra has to be exerted upon the tow-rope while the increase is going on, with which resistance has nothing to do. If the speed becomes steady again, but greater than before, the towing-force becomes once more equal to the resistance, and—generally speaking, at any rate—both are greater than before. Resistance, then, is a quantity which becomes greater the greater the speed at which the resisting body is moved. In a ship propelled, say, by a screw, the resistance is no more overcome by the pull of a rope, but by the push which the screw gives through the shaft to the structure of the ship; the force of this push has to be given by the engines, and is thus intimately connected with the power of

the engines. This being so, it is impossible for me to avoid any allusion to horse-power, and, far from so doing, I intend at one place to trace broadly the connection between the two; but, for the most part, I shall keep to the simpler subject of resistance, avoiding language which could be intelligible only to those engaged in the study of phenomena connected with ships. In speaking of resistance, too, I shall confine myself on this occasion to resistance in still water only, and shall suppose the vessel experiencing resistance to move only in the line ahead, without being in any way affected by sideways motion or by careening under the action of the wind. I say this, because the question is sometimes asked with regard to model experiments, whether they have been made in still water, or in water agitated to represent a stormy sea; and there are those who object to trying ships in calm weather upon the measured mile, because they think it does not give a fair idea of what the same ships would do at sea, apparently overlooking the advantage of being able to compare the performance of ship with ship, a comparison which can only fairly be made when surrounding circumstances are identical; at present there is no standard of measurement for the agitation of the sea, except the zero point of calmness, and it would therefore seem just as well to get all the data for comparison when waves are at that zero.

I purpose treating my subject to some extent historically, mentioning the names of those most intimately associated with it, and discussing some of the broad features of their work. Towards the close I intend to say something about the dimensions of steamers.

Early last century Sir Isaac Newton, in his *Principia*, touched upon the subject. He does not appear to have made any experiments; nor does he very fully record his investigations upon it.

In the course of the century, experiments were conducted by *savants* connected with the French Academy of Science. The object they seem to have had before them was to find the resistance to motion of a wedge-shaped body, according as the angle of entrance was more or less acute.

But if asked to mention the name most closely associated with experiments upon the resistance of bodies in water, one would, before the last ten years, have naturally answered Colonel Beaufoy. In the last decade of the last century he worked hard at the subject, aided partly by a "Society for the Improvement of Naval Architecture," but chiefly dependent upon his own resources.

We learn from his son and editor that "Colonel Beaufoy had made his first experiments upon the resistance of solids moving through water before he was fifteen years of age; and he pursued the subject with unabated zeal until within a few months of his death. His attention was first drawn to the subject in consequence of his hearing stated one evening by an eminent mathematician, as an axiom generally received by naval mechanics, that a cone drawn through the water with its base foremost experiences less resistance from the fluid than with its apex foremost. This paradoxical assertion excited young Beaufoy's curiosity, and before bedtime, with the assistance of a neighbouring turner, he ascertained the fallacy of the alleged opinion by making the experiment in one of the coolers of his father's brewhouse, the large bunch of counting-house keys being put in requisition for a motive power."

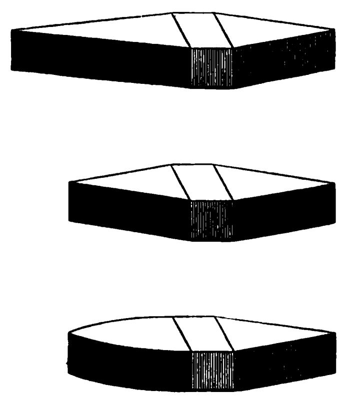
The result of this first experiment, as refuting the opinion he had heard, seems to have clung tenaciously to the mind of the investigator; he confirmed it again and again, and—annexed to the record of some of his experiments—made a special note that, "contrary to the received opinion, a cone will move through the water with less resistance with its apex foremost than with its base."

Beaufoy's more important experiments were made in the Greenland Dock, near London, at which place he had a run of 400 ft., and a depth of water of 11 ft. His experiments included a determination of the value of surface friction, and of the resistance of a number of bodies of large size and all sorts of shapes—cubes, cylinders, squares, flat boards moved square to the line of motion, and flat boards moved obliquely. Most of the bodies tried were below the surface, being attached by

vertical legs to a floating body of which the resistance was known; but a great many also were tried at the surface. In no case did the forms he used approach to the shape of a ship —those shown on Fig. 1 being, perhaps, the nearest thereto—

*Fig. 1.*

THREE OF THE FORMS EXPERIMENTED UPON BY COLONEL BEAUFOY.



the experiments being aimed rather at determining such questions as the effect of different angles of wedge-shaped entrances, and of different angles of run; the difference of resistance between a flat-sided entrance and a round-sided entrance, and so forth. The record of the results has been published with scrupulous care, and contains many matters connected with resistance of ships of great interest.

The next name I bring before you is that of Mr. Scott-Russell. A mathematician and a practical shipbuilder, to him belongs the credit and attaches the interest not only of enunciating and elaborating a distinct theory, but also of building ship after ship in accordance with that theory. Some of those ships have stood the test of years of practical handling, fulfilling the intentions of their designer, and giving satisfaction to all concerned; while one at least has been a fruitful source of disappointment, not so much, perhaps, on account of the size and proportions of the vessel, as because her engines belong to a date anterior to that when sufficient care was or could be paid to the development of power with a minimum expenditure of fuel.

It is not my intention to enter fully into Mr. Scott-Russell's views, nor to notice the steps which led to them, and I shall be content to summarize the conclusions drawn from his theory. First, as to the form of the lines he advocates—the lines of the fore body are known as harmonic curves or curves of sines, while those of the after body belong to the family of trochoids. Next, as to total length and length of fore and after bodies—the theory gives a minimum for each of these according to the speed desired, and a ratio, depending on that minimum, of six parts in length for the fore body to four parts for the after. The total length thus required is exemplified by the following table:—

| Speed in knots. | Total length in feet. |
|---|---|
| 10 | 96 |
| 14 | 187 |
| 18 | 309 |

in which the first column represents the speed desired, while the second gives the minimum length, according to the theory, suitable for that speed. This relation of length to speed was one of the most valuable results of the wave-line principle, as a step, at least, in the right direction; though the way in which one difficulty of the case was met is far from satisfactory. The difficulty is that, while the lengths of the two bodies are fixed by considerations of speed, there is still the consideration of capacity to be dealt with. Scott-Russell's method was to put in a parallel middle body between the two ends already fixed, the new part being sufficient for the purposes of the particular ship. Thus the "Great Eastern" has a length of fore body of 330 ft., and of after body of 220 ft., these lengths being made great enough for any speed the ship was ever likely to attain, while between them was inserted a length of 120 ft. of parallel middle body in order to give to the ship a sufficiency of carrying power. To this matter I shall again refer.

So much, then, for the form of the lines and for the length of the ship. The last matter to be noticed is the area of midship section—*i.e.*, Mr. Scott-Russell's view of the effect of

area upon the resistance and horse-power of a ship. His language on the subject has, I think, been not sufficiently guarded, and has consequently been the source of very decided error. He writes, for instance, that, "if a ship crosses the Atlantic from England to America, it has to excavate a canal 3,000 miles long, and as large transversely as the greatest section of the ship," and from this consideration draws the conclusion that "to give a ship length, and reduce the area of the ruling section to a minimum, is the first step to securing a fast and economical ship." But his argument is illogical, according, at any rate, to the more advanced reasoning at present applicable to the mutual behaviour of ship and water, and his conclusion, as it stands in the words quoted, utterly unsound. The words, however, do not, I think, represent his sober view of the case. What he says in another place is that, when the lines of the ship are got out according to the wave-line principle, then the horse-power necessary is in proportion to the area of midship section—*i.e.*, if two ships are both to go 10 knots, and both have the necessary length of 96 ft., and both have wave-line bows and sterns, yet differ in the area of midship section, the one, perhaps, having half as much area again as the other, then that one which has the greater area will experience the greater resistance, and require the greater horse-power just in proportion to that excess. This, which I believe to be his real view, appears to be at least not very far from the truth, while it does not lend any countenance to the far broader conclusion which I have quoted above.

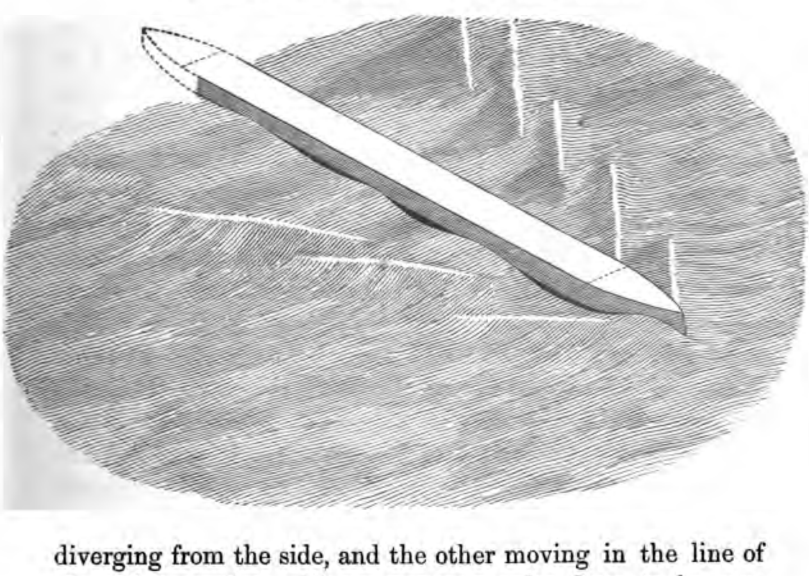
The next investigator, whose work must for a short time engage our attention, is one well known to a Glasgow audience —the late Professor Rankine. It does not require any words from me to tell of his great mathematical ability, the extent and variety of his writings, or the reputation in which he is held.

In connection with the subject of the resistance of ships, part of the useful work which he did was to classify, under different heads, the several forces obstructing the forward motion of a ship, and thus making up the total resistance

which she experiences. I will mention the two most important of these to facilitate the consideration of our subject further on. The first of these forces or resistances is that due to the rubbing of the surface of the ship against the particles of water past which she moves. Resistance due to this cause affects any body moving through the water—even a flat board moved edgeways experiences it. This force is generally known as the surface-friction resistance; it is greater, of course, the greater the area of the surface and the greater the speed at which the surface is made to move. The second is the resistance due to the formation of waves. Every one has noticed that when a ship is moving a number of waves accompany her, many in number but small in size if her speed is small, fewer in number but of considerable height if her speed is great. In Fig. 2 two series of waves are shown, one

*Fig. 2.*

DOUBLE SERIES OF WAVES RAISED BY BOW OF A VESSEL HAVING A LONG PARALLEL MIDDLE BODY.



diverging from the side, and the other moving in the line of the ship's motion. These waves require force to be continually exerted by the ship upon the water, else they could never be maintained, and this force constitutes the resistance

of which we are speaking. As we shall see by-and-by, the resistance due to the formation of waves is very small at low speeds, surface-friction resistance monopolising the whole; but as the speed increases so this part of the resistance grows in importance more rapidly than that due to surface-friction, until it, in turn, has most influence in hindering the forward motion of the ship.

With a desire to get a result which might be of practical utility for determining the resistance which any well-formed ship would experience, Rankine devised a means for obtaining what is well known by the name of "augmented surface" of a ship. His first step in the matter was to assume that the ship was sufficiently well formed to have none of the wave-making resistance which we have been considering, but only the surface-friction resistance. From Weisbach's experiments upon the flow of water through pipes, he deduced that the resistance of a board 1 sq. ft. in area moving edgeways through the water has a resistance of 1 lb. at 10 knots, varying for other speeds as the square of the speed. For the area of the surface over which this resistance per square foot has to be counted, he held that it is not sufficient to take the immersed surface of the ship because, although the ship be going at a definite speed, say, 10 knots, through the water, still each individual foot is not moving at 10 knots in reference to the water in contact with it—the speed being in some cases below, and in others above 10; the general result being that a higher resistance has to be taken than that due to a surface equal to the immersed surface of the ship moving at a speed of 10 knots. This point may be illustrated by a reference to Fig. 3. The ship is going at 10 knots, or what comes to the same thing, the water is meeting the ship at 10 knots. In the first portion of the length—say, from A to B—the water is retarded, due to the insertion of the body, the relative speed being reduced below 10; in the second portion—from B to C—the water is accelerated, the relative speed exceeding 10, while from C to D the water is again retarded, the relative speed being again less than 10. The result is, according to Rankine, that the immersed area, taken at 10 knots, would not be sufficient to

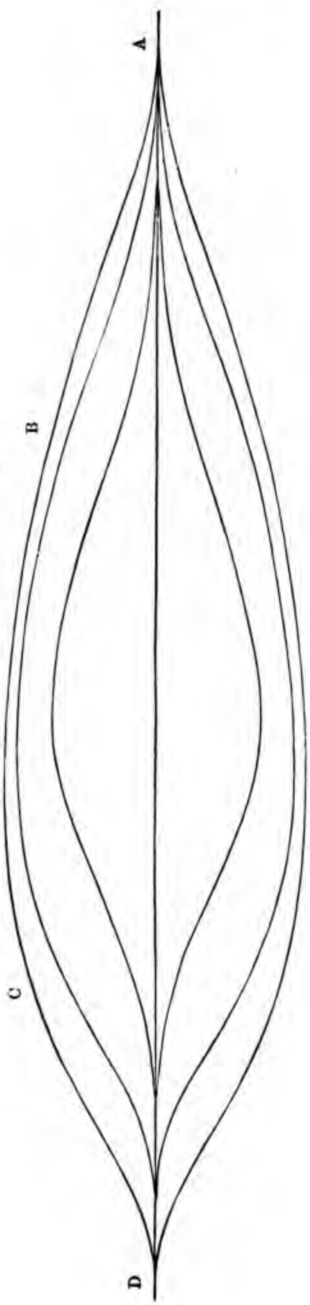



*Fig. 3.*—GREAT RAVEN (Scale about $\frac{1}{20}$th).

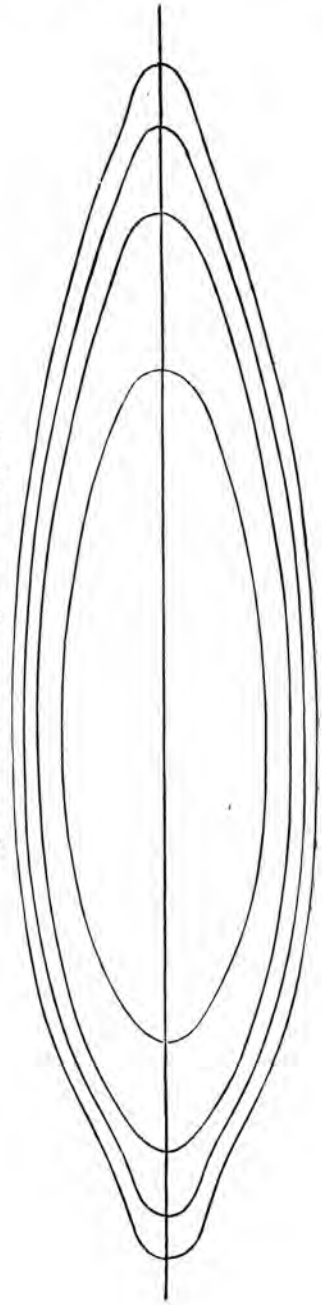


*Fig. 4.*—GREAT SWAN (Scale about $\frac{1}{20}$th).

give the resistance actually experienced, and a "co-efficient of augmentation" is necessary; whether it be the speed that is augmented, or the surface, is practically immaterial; Rankine preferred to consider the surface, and that surface, when augmented, he called by the name of "augmented surface." To get the value of that augmentation he made use of an algebraic artifice, which has always seemed to me to carry empiricism on its face. The assumption on which it rests involves the supposition that, even when the water-line is as sharp as that shown in Fig. 3, the greatest retardation of which I have spoken occurs at the very nose of the vessel, and as a consequence of this that the bow-wave rises to its highest at that place. It requires little observation of vessels to know that such is not the case. From resistance Rankine passed to horse-power, and has published comparisons for several ships between the real power actually required at a certain speed and the power as calculated by his method, the agreement in all cases published being wonderfully close. An element of unsatisfactoriness about these comparisons, and one that has been pointed out by Mr. William Denny in one of his papers, is that some of the same ships had been tried at another speed besides that for which Rankine made the comparison; and that, if another comparison be instituted for such other speeds also, the results are far from showing the same agreement as before. The explanation of this is that the surface-friction resistance, as taken by Rankine, of 1 lb. per square foot at 10 knots, is far too high, and allows margin for a fair amount of wave-making resistance, which he regards as non-existent, but which does nevertheless exist. The calculated result at some one speed may, therefore, exactly agree with the observed result; but make the comparison at another—say, at a lower speed—the wave-making resistance is less important in relation to the surface-friction resistance, while the calculation gives it as much importance as before, and the result is that the calculation is in excess of the observed figure.

I have said so much in criticism of Rankine's method, because it has been and still is welcomed as something

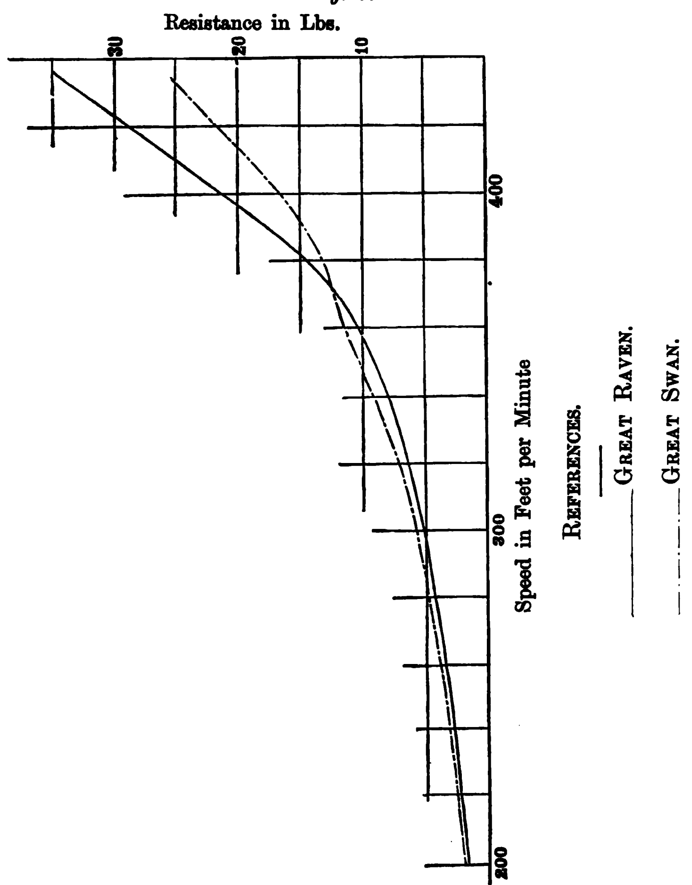
tangible—something from which one can, without any data derived from previous ships, calculate on first principles the speed of a ship for a given horse-power, or conversely the horse-power of a ship for a given speed. Want of time and the more purely theoretical nature of the subject will prevent my going into the question of stream-lines, the nature of which Rankine investigated mathematically, and with which his name and reputation will be far more lastingly associated.

I come now to mention Mr. William Froude's work with models at his experimental tank at Torquay. It is not quite ten years since that work commenced, and with it quite a new era in matters connected with the resistance of ships was inaugurated. Although it was only the later years of his life that were given to the practical consideration of the subject, still all through his life matters connected with boats and ships, and among them that of resistance, engaged his attention, and called forth his power of observation. He had repeatedly noticed, for instance, that the breast of swimming birds became protruded as they increased their speed, the round bow being followed by a hollow portion situated at, say, one-fifth of the length of the fore-body of the bird from the front of the breast. [The practical advantage of such protrusion was sought for latterly by a comparison of the resistance of two model yachts, the lines of which are given in Figs. 3 and 4, the result proving, as shown on Fig. 5, that, while the fine-lined boat "Great Raven" was much the better at low speeds, the "Great Swan" became the better in a most unmistakable manner when the speed was sufficiently increased.]

Before much could be done in the way of applying the data obtained from the resistance of a model to the case of a ship, it is evident that some scale of comparison was necessary. Phenomena, such as ricocheting, which might be expected to occur at a speed, say, of 10 knots, with a very small model, would certainly not occur at 10 knots with a ship 100 times the size of the model; and it is thus at once evident that, if there is any connection between ship and model, any representative speed for the one must be very different from the corresponding speed for the other. One of Mr. Froude's

happiest strokes of genius was the determination not only that such connection does exist, but also what the nature of connection between ship and model really is. I will not give the "law of comparison," as it is called, couched in its technical language, but will rather give an arithmetical example

*Fig. 5.*




of its application. Suppose a model 10 ft. long, and a ship 250 ft. long; for such a pair the speeds at which the resistance may be compared are 1 knot for the model = 5 knots for the ship, 2 for the model = 10 for the ship, 3 for the model = 15 for the ship, and so on; and at these corresponding speeds

the resistance of the ship will be $25 \times 25 \times 25 = 15625$ times the resistance of the model. This law was demonstrated by Mr. Froude on mathematical principles, and the application of it practically proved by experiments upon models similar to one another, but of different size.

While Sir E. J. Reed was Chief Constructor to the Navy, and with his advice and help, Mr. Froude proposed to the Admiralty to conduct a series of experiments, offering his own time, provided the necessary expenses were borne by the Department. The offer was accepted, and in 1872 the experiments were inaugurated. The tank used is 270 ft. long, 40 ft. broad, and was at first 10 ft. deep; its depth has since been lessened by 6 inches. The first few months of experimenting were occupied with the matter of surface-friction, which, as we have seen, is one of the important elements going to form the resistance of any body moving in water. Among the substances tried were paint, paraffine, and calico; but for the interesting results obtained I must refer to the published report, contenting myself with giving here one single figure. I have spoken of the value attached by Rankine to surface friction as too high; the value, as deduced by Mr. Froude, for paint or varnish amounts to about $\frac{6}{10}$ lbs. per square foot of a surface, the total length of which is 120 ft., at a speed of 10 knots.

After the experiments upon surface-friction, the more important work with models commenced. This has gone on to the present time, because, although Mr. Froude died two years ago, the Admiralty have too much reason to appreciate the advantage of the establishment to think of discontinuing it, and have placed the superintendence of it in the hands of Mr. R. E. Froude, who from the commencement has identified himself with this portion of his father's work, and to whom much of the present perfection in the apparatus employed is due. The models tried have, with few exceptions, been made of paraffine, of which a sample has been kindly lent me by Mr. R. E. Froude for the purpose of this lecture. The number of models formed has been 130, most of which, moreover, have undergone several modifications,

increasing thereby very considerably the actual number of forms that have been experimented upon. The lengths of the models have varied from 6 to 20 ft.; 12 or 13 ft. being the outside length for which the apparatus is designed, while the larger ones have been made in two halves and jointed. They have represented in some cases actual ships; in other members of a series of forms intended to bring out certain definite results.

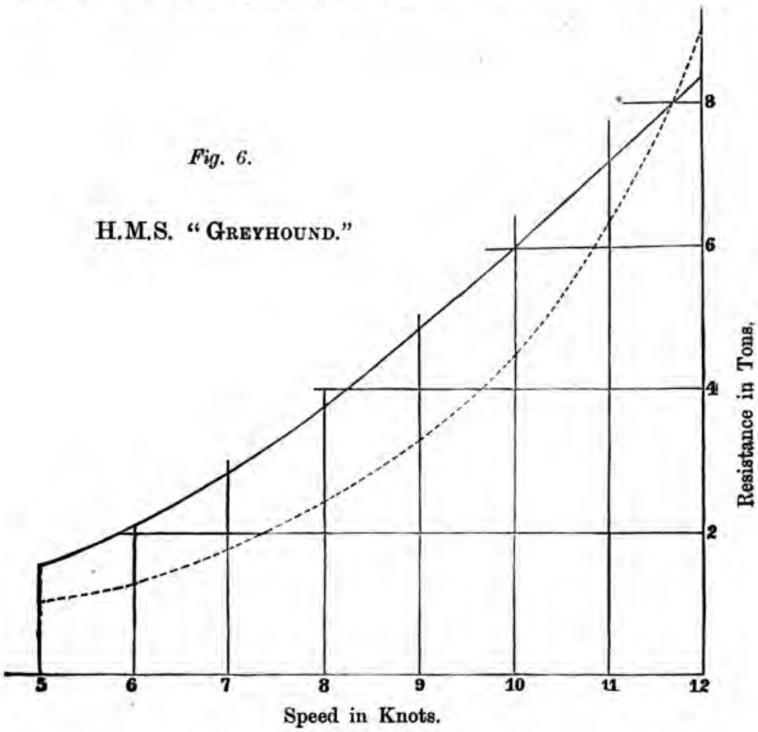
Of models of actual ships, one of the most important, in view at least of the test that it gave of the accuracy of the experiments generally, was that of the "Greyhound." In her case not only was the model tried, but the resistance of the ship herself was experimented upon most exhaustively; H.M.S. "Active" being used to tow her, and the resistance at various speeds measured with a dynamometer. These experiments with the ship were conducted under three conditions of draught, and each condition of draught was varied by from two to four different conditions of trim. All of these conditions were represented to scale upon the model, and thus a great number of comparisons between ship and model were rendered possible. For the detailed account of the comparison I refer you to the published report, and will only mention now that each alteration in condition for the ship caused an alteration in resistance which agreed most closely with the corresponding alteration for the model; and that, after due allowance for causes of which the law of comparison does not take account, the resistance of the ship might have been closely predicted from that of the model.

In Fig. 6 is illustrated the curve of resistance of the "Greyhound," as compared with the curve of resistance—shown by the dotted line—as it should be according to Rankine's method of augmented surface, the illustration being borrowed from a note upon the "Greyhound" which I contributed to *Naval Science* at the time of the publication of the experiments. It will be seen that at one speed the two curves agree exactly; but only at one speed. This, as I have said before, helps to explain why Rankine's method has given some good results.

Another actual ship, the model of which was tried, is the "Merkara," built at Leven Ship-yard. Fig. 7 represents the curve of resistance for the model of this ship, and it may be interesting if I explain the diagram in some detail. The little cross-marks represent actual experiments made, and denote both the speed at which they were made and the

*Fig. 6.*

H.M.S. "GREYHOUND."

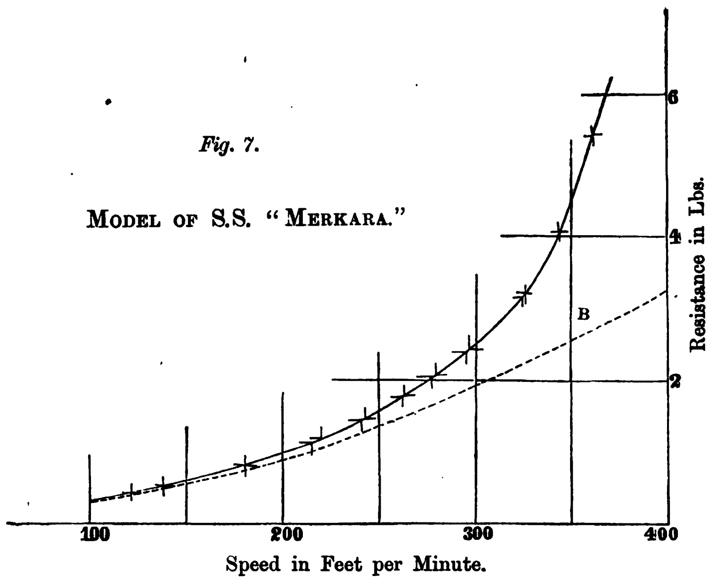



resistance which the model encountered; thus to take any one of them, measure its position horizontally along the base according to the scale shown below, and the measure gives the speed; next measure the position vertically according to the scale shown on the right hand side, and the measure gives the resistance. The advantage of the curve passing through the spots is two-fold: (1) it forms some sort of a check upon the accuracy of the experimental data denoted by the spots, a fair curve being what one would most naturally

expect to obtain; (2) it unites and extends the information derived from the experimental data, the resistance at a few speeds being extended to resistance at any speed whatever within the limits covered by the curve. There is no spot, for instance, at the speed marked 300 feet per minute, but the resistance at that speed is nevertheless shown, the reading

*Fig. 7.*

MODEL OF S.S. "MERKARA."




being 2·5 lbs. Below the curve of resistance is another curve, marked B, representing at any speed the amount of friction pertaining to a surface of the same length and area as that of the model, the data for this curve being obtained from the entirely independent and previously-conducted surface-friction experiments already mentioned. It will be seen how nearly the two curves coalesce at low speed, showing that then the resistance is entirely, or almost entirely, due to surface-friction; while, as the speed gets greater, the two curves diverge, showing the growth of some other part of the resistance, that part being—as has been explained—chiefly due to the formation of waves which diverge from the side of the vessel, and require it to exert force for their continual reproduction. I have mentioned that one of the

advantages of passing a curve through the spots derived from experiments is to check the accuracy of the experiments by the fairness of the curve. I do not claim fairness for the curve we are considering, but still the curve did this: it showed what experiments were most likely to be in error, and at what speeds the resistance was furthest from being a well-determined quantity. Doubtful experiments were repeated, and experiments at other desirable speeds made, with the result that the unfairness of the curve became one of the features established as surely as anything else connected with it, the multiplication of black spots where the humps and hollows occur indicating multiplication of experiments authoritative of those humps and hollows.

I must at this point say something about the connection between the resistance of a model and the indicated horse-power of a ship. As already explained, resistance of a ship can, by Mr. Froude's law of comparison, be deduced from the resistance of the model, by multiplying the speeds of the model by one figure and the resistance of the model by another—certain corrections well determined by experiment having also to be introduced. The next question then is, What is the connection between the resistance and the indicated horse-power of a ship? To understand this, we must remember that power involves the quantities force and speed, while resistance involves only the quantity, force; for instance, both a weak man and a strong man may be able to employ the whole day in lifting weights of 50 lbs. from the ground to the top of a house, but the man who is the stronger will be able to lift with the greater rapidity—twice as fast indeed if he has twice the power. Knowing what a man can lift and the speed at which he can lift it, we have a measure of the power of that man; and so too, knowing the resistance of a ship at any speed, we know the power required for that speed. The development of this power by the engines would not, however, be sufficient, the screw from various causes not receiving more than a share of the power given out by the engines, that share being often as small as 40 or 50 per cent. of the whole. What those causes are I do

not intend now to consider; suffice it is to say that they can be considered, and the amounts due to them allowed for in at least an approximate way. To return to the "Merkara." That ship was tried progressively upon the measured mile, in the manner in which all of Mr. Denny's ships are tried. The data so obtained were compared with the resistance of the ship as obtained from the model, due allowance being made for the causes just mentioned; and the resulting comparison showed an extremely close agreement. I may perhaps put the matter in a more instructive way, as follows:—The principles affecting the difference between real power of engines and power effectively employed in driving the ship having been previously investigated, the "Merkara" and other ships supplied the means of determining the actual values of some of the items of difference. These values were such as might reasonably be expected, and form part of the data which is now available for passing from the resistance of the model of a ship not yet built or tried to the horse-power required to be developed by the engines of that ship in order to drive her at any particular speed.

A natural question in connection with the Torquay establishment is, What has been the practical outcome of the work there? In answering this, it must be borne in mind that the tank was instituted for the purposes of the Admiralty, everything connected with it being the property of that Department; the results, therefore, bear chiefly upon Government ships. The models of several ironclads were subjected to experiment; for instance, the "Devastation," the "Dreadnought," and the "Inflexible"—the proposed horse-power in the case of the latter ship being modified on account of the results obtained from her model. The design for the "Polyphemus," the wonderful torpedo-ram at present under construction at Chatham, was altered once and again from various causes, one cause being that the form was not such as might be expected to give the best speed results. In the various stages models of her were tried at Torquay, and the results with these had their influence in the alterations made. The speed which the "Iris" would obtain was predicted from

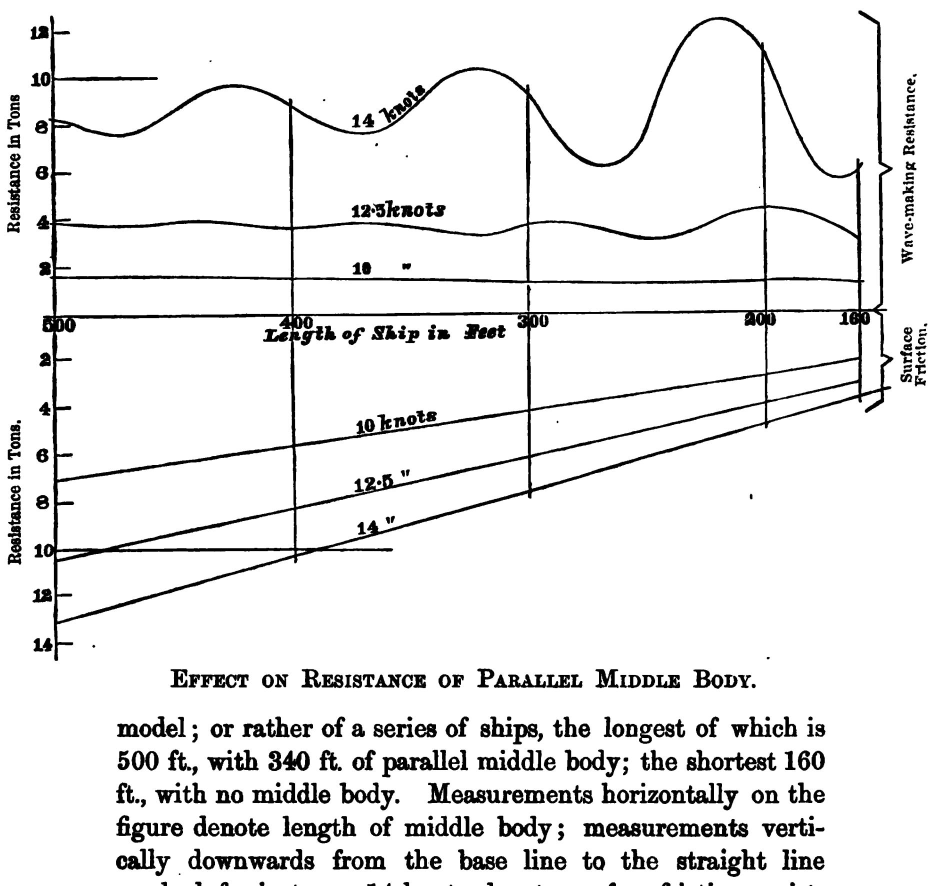
experiments made with her model; even the lines of that vessel were influenced by suggestions from Torquay, based upon the results obtained from a series of models, the lines actually suggested being altered at the Admiralty to suit certain requirements of the ship. And to Mr. Froude belongs the further credit of having pointed out where the fault lay when at first she proved a non-success, and of suggesting what led, in the hands of the Admiralty officials, to the great speed of 18½ knots which the vessel ultimately attained. Besides these larger vessels—and with them I should mention the three circular ironclads built in Russia to Admiral Popoff's design—experiments upon models of various corvettes, including the "Comus," built by Messrs. J. Elder & Co., gun-boats, torpedo-launches, &c., have all found place, the number of experiments, and sometimes too of models, made in each case, being very large, and the object sought being something specially interesting in connection with the class of vessel considered.

The question of the area of the midship section has often arisen in connection with the experimental work; it arose at the time of the experiments upon the "Iris," and at many another time besides. The invariable result was that up to a certain limit of fineness a vessel with small area of section and full lines might always be improved by increasing the area of section—increasing, for instance, the breadth—and making the lines finer. I remember the comparison of the models of two ships, one of which had 5 ft. more breadth than the other, but lines finer to a corresponding degree. The result showed that the broader ship would, with the same resistance, go fully a knot faster than the narrower one.

Of one extremely interesting series of experiments made at Torquay I have yet to speak—a series in which the fore body and after body of the vessels were kept absolutely the same, while between them came a parallel middle body, the length of which could be and was subjected to variation. The total length of the model—which was, as usual, of paraffine—was originally 20 ft., 3·2 of this representing fore body, 3·2 after body, and the other 13·6 parallel middle body.

Pieces were cut from this middle body by easy stages, the two halves being jointed up again after removal of each piece. In this way many variations were made, the length of middle body ranging from 13·6 ft. to ·0. Fig. 8 shows the resistance, not of the model, but of a ship similar to the

*Fig. 8.*




Effect on Resistance of Parallel Middle Body.

model; or rather of a series of ships, the longest of which is 500 ft., with 340 ft. of parallel middle body; the shortest 160 ft., with no middle body. Measurements horizontally on the figure denote length of middle body; measurements vertically downwards from the base line to the straight line marked, for instance, 14 knots, denote surface-friction resistance, due to an area equal to that of the ship having the length at which the measurement is taken; measurements from the straight line to the wavy line above, also marked 14 knots, denote the total resistance as deduced from the model

corresponding to a ship of the length taken; so that measurements from the base line to the wavy line give excess of total over surface-friction resistance, the speed being always 14 knots, that excess being chiefly due to the maintenance of waves. It will be noticed how enormously this wave-making resistance varies, the amount at one length being double what it is at another; and the cause of this is the strangest part of the whole. Fig. 2 represents the two series of waves raised by the fore-end of the vessel, one diverging from the side, the other moving square to the line of motion. Of this latter series, each successive wave is the creature of those that precede it, and its position is therefore fixed, apart from any question of what part of the vessel it ought or ought not to come at. That member of the series of waves, then, which comes near the stern, where the water-lines are converging, comes at a different part of those lines, according as the length of middle body is more or less, and at one time is helping the vessel forward, at another keeping her back; hence the alternation between high and low resistance which is expressed on the diagram. When the length of middle body is not very great, then the greatest variation in this part of the resistance occurs, because then the wave is greatest, and its effect most pronounced; when the length of middle body is great, then the wave causing the effect is less pronounced, and the effect itself smaller. At lower speeds, also, as shown by the straighter lines on the figure, the effect becomes less, and even disappears. In view of what is exhibited by this diagram, it is evident that Mr. Scott-Russell's plan of putting in a quite indeterminate amount of parallel middle body is not altogether free from objection.

I should like to speak of Mr. Froude's interesting experiments, made first before the British Association at Bristol, upon the flow of water through pipes, with the object of demonstrating that a ship has no such thing to experience as direct head resistance, and that if it were not for surface-friction and the raising of waves, a ship, once started, would go on without the use of her engines. This matter I must exclude for want of time, on the same ground that I avoided

doing more than referring to Rankine's stream-lines and forms constructed from them—that it has to do with the pure theory of the subject, and has, at present at any rate, only an indirect bearing upon the practice.

It has been suggested by several, and among them Mr. Pearce in the opening lecture of this series, that private shipbuilders should establish an experimental tank similar to the one at Torquay. Such a suggestion is of the highest value, and well worthy of being carried into practice. If it had not been for the experiments made at Amsterdam by Dr. Tideman, supplemented as they subsequently were by the further experiments upon Loch Lomond, how could any one responsible for the speed of the "Livadia," how could Mr. Pearce, have been certain about the speed which that remarkable vessel attained? In this respect, in the matter of attaining and far exceeding her predicted speed, she was indeed a triumph. In using the word I do not wish to imply an admiration for her form, or belief in its being well adapted to an economic relation between speed and power, but I do feel that to her designers and builder is due the credit of distrusting all the empirical methods which they might have brought to bear upon the question of her speed, and of trusting to data obtained so laboriously from carefully-conducted experiments upon models. The course which has had so satisfactory an outcome in the case of the "Livadia" might be extended with great advantage; and if the opportunity of conducting them existed, experiments might be made, directed not only to decide the horse-power required by any particular ship but also to determine the relative superiority of two or of any number of ships. One matter which will probably depend for its solution largely on the results obtained in an experimental tank is that of length; and along with it the ratio desirable between the three dimensions of a vessel—length, breadth, and draught. You know what huge strides have been made in recent years in the direction of length. In this Exhibition there are models of the "Iberia," the "Arizona," the "City of Berlin," and the "Servia," ranging in length from 449 ft. to 515 ft.; while, not

represented in the collection, but at present under construction at Barrow, is the "City of Rome," a ship which will have a length of 546 ft., or within 125 ft. of the length of the "Great Eastern." In passenger ships the advantage derived from great length in the way of allowing of plenty of room for state-room accommodation, all the rooms, or a large proportion of them, being next to the ship's side, is no doubt very great; but I cannot help thinking that a mistaken notion of economy of engine power has a great deal to do with the fixing of the dimensions, so many beams to the length, and the more the better, being considered in some form a measure of goodness for speed. Let us for a moment consider what is the primary question which may be supposed to meet the designer who is desirous of producing the best possible ship, from an economic point of time, all other considerations being for the time suppressed. It may, I take it, be broadly stated as follows:—Required a certain amount of carrying capacity, and a certain speed to be realised, what dimensions and form of vessel are best calculated to secure both economy and efficiency? This may, with two assumptions, be reduced to the following:—Required a certain displacement and a certain speed, what length of ship will require the least horse-power to drive her? The two assumptions in this modified form of the question being—(1) That the carrying capacity is, within the limits of dimensions likely to be suitable, proportional to the displacement; (2) that the best type, as expressed approximately by fineness of ship, has already been determined upon—both of which assumptions would, in an exhaustive investigation, have to be verified or amended. It will be seen that in the question, as thus put, no consideration of ratio of length to breadth occurs; the designer, provided he has full experimental data to assist him, determines first the length: the breadth, or rather the product of the breadth and draught, then becomes determinable from the consideration that a certain displacement has to be obtained with the length as determined, and a fineness of ship as assumed. To illustrate the foregoing, I will adduce data obtained from some of the Torquay experiments. Among

the models there tried was a series of about seven in number, all of which had the same sections—sections which gave lines proved by experiment to be good. These sections, all at the same distance apart in the same model, were at different distances in different models—the lengths of vessels thus produced ranging from 6 to 15 feet; the varying lengths were accompanied by a definite breadth of 1·92 feet, and a definite draught of ·72 feet ($\frac{3}{8}$ the breadth). The models were all tried experimentally over a large range of speed, and from them could be deduced the resistances of any ships similar to them. If a certain displacement were fixed upon, then each model might be taken to represent on an ascertainable scale a ship of that displacement, and from the model the resistance of the ship deduced. The dimensions of such ships would vary among themselves, each depending for the relation of length, breadth, and draught upon the particular model of the seven to which it was similar. One of this number of ships would have less resistance than all the others, the shorter ones being too short and the longer ones too long for the speed and displacement desired. The following Tables give specimens of approximate conclusions deduced in the manner indicated. The dimensions denote not necessarily the members of the series of ships which would be absolutely best—because some uncertainties exist with regard to the data which have never been completely cleared up; they denote rather ships of a length beyond which little if any gain might be expected. The first Table gives such dimensions for three ships, all of 4,000 tons displacement, intended for 10, 14, and 18 knots respectively. The second and third give dimensions for three ships intended for 14 and 18 knots respectively:—

4000-Ton Ships.

| Speed in knots. | Length. | Breadth. | Draught. |
|---|---|---|---|
| 10 | 293 | 51 | 19 |
| 14 | 318 | 49 | 18 |
| 18 | 360 | 46 | 17 |

14-KNOT SHIPS.

| Displacement in tons. | Length. | Breadth. | Draught. |
|---|---|---|---|
| 1,000 | 222 | 29 | 11 |
| 4,000 | 318 | 49 | 18 |
| 7,000 | 372 | 60 | 22½ |

18-KNOT SHIPS.

| Displacement in tons. | Length. | Breadth. | Draught. |
|---|---|---|---|
| 4,000 | 360 | 46 | 17 |
| 7,000 | 400 | 58 | 22 |
| 10,000 | 437 | 66 | 25 |

In determining the above, length is the dimension which in all cases has been first deduced, breadth and draught then following to make up the required displacement. It will be readily seen that the dimensions noted in these Tables differ very largely from those of actual ships, both in the absolute length of ship and also in the ratio of length to breadth. Compare, for instance, the dimensions of the 10,000-ton ship, intended to go 18 knots, with the dimensions of the "Servia," and the contrast will appear very marked. (I believe the "Servia" is to have a load displacement of some 10,500 tons; in which case the length figure in my Table would have to be some 20 ft. greater than it is, leaving a difference still of over 50 ft. between my figure and the length of the actual ship). The much greater breadth and the greater draught of the ship in the Table are, it is true, decidedly open to objection—the former because it would involve extra weight of material if the ship were built to fulfil Lloyd's requirements, the latter because few ports would admit of the ship's entry. I will not attempt to answer these objections further than by saying that both Lloyd's rules and the depths of water in ports are intended to meet the requirements of ships as they are at present built, and not as they may require to be built in the future; and I will not attempt a further answer, because it would be quite beyond my intention if I were to seem to claim for the dimensions noted that they are the best possible, or that the type of vessel on which they are based cannot be excelled. As a matter of fact, I know that,

in some respects at least, that type can be excelled, and that for the better type other dimensions would be more favourable. My object is rather to show how much there is to be learnt on the subject—matter that can only be learnt by the use of an experimental tank. But I do venture to predict that, when matters of speed have been more thoroughly investigated, ships of very different dimensions from those at present in fashion will come to be built—ships, too, in which the breadth bears a much higher ratio to the length. Of late years much has been done on the Clyde towards getting careful data connected with speed. Mr. William Denny strongly advocated, and himself adopted, the plan of trying the ships built by his firm at several speeds (four or five in number), ranging between the lowest and the highest that the engines are possible of maintaining, two runs being in every case made for each speed, one with and the other against the tide. Previously, one speed with each ship had had to suffice, the data obtained from it—although now acknowledged to be inadequate—being all that was available for future use. Mr. Denny's plan has now been adopted by several other builders on the river. With the data obtained from speed trials, several gentlemen—notably Mr. Inglis, Mr. Kirk, and Mr. Mansel—have been working very sedulously with the view of sifting it, of drawing all the information they can from it, and of getting it into a form which may render it handy for application to the case of a new ship required. The experimental tank is necessary for taking up the work where all these gentlemen are bound to leave it, and for investigating the effects of single alterations instead of alterations *en grosse.*

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The books and papers from which much of the foregoing information has been obtained are as follows:—

Col. Beaufoy's Nautical and Hydraulic Experiments. Printed for private circulation.

The Modern System of Naval Architecture. J. Scott-Russell, F R.S. Published by Day & Sons.

Papers on the Wave-line Principle of Ship Construction. J. Scott-Russell, F.R.S. *Transactions of the Institution of Naval Architects*, years 1860 and 1861.

Shipbuilding, Theoretical and Practical. Professor Rankine, and three others. Published by William Mackenzie.

Report on the Frictional Resistance of Water. W. Froude, F.R.S. Published by Taylor & Francis.

Report on Experiments for the Determination of the Resistance of . . . . . . H.M.S. "Greyhound." W. Froude, F.R.S. Published by Taylor & Francis.

(See also Paper, *Transactions of the Institution of Naval Architects*, for 1874.)

Paper on Experiments upon the Effect produced on the Wave-making Resistance of Ships by Length of Parallel Middle Body. W. Froude, M.A., F.R.S. *Transactions of the Institution of Naval Architects*, for 1877.

(For extension of this Paper, see Paper on the Leading Phenomena of the Wave-making Resistance of Ships. R. E. Froude. *Transactions of the Institution of Naval Architects*, for 1881.)

# THE RIVER CLYDE AND HARBOUR OF GLASGOW.

BY JAMES DEAS, C.E., CLYDE NAVIGATION TRUST.

*ON FRIDAY, 11th MARCH, 1881.*

THE object of my lecture is not to trace the course of the Clyde from its rise among the hills of Lanarkshire and Dumfriesshire till its waters mingle with those of the mighty ocean—not to describe its ancient margins, its gigantic falls, its pleasant pastoral lands and fertile vales, its prolific orchards or its wooded slopes—nor to offer any conjectures concerning its state and depth during the ice period, or when the primitive inhabitants residing on its banks did business or took pleasure on its then clear waters in those rude canoes which from time to time have been disinterred from the deposits of centuries—but to describe, as shortly and clearly as I can, the character and magnitude of those works which have, within the last hundred years or so, converted it, between Glasgow and the sea, from a shallow stream, navigable only by fishing wherries of at most 4 or 5 feet draft, and fordable even 12 miles below Glasgow, to a great channel of the sea, bearing on its waters the ships of all nations and of the deepest draft, thus bringing to this City of the West the fruits and ores of Spain, the wines of Portugal and France, the palm-oil and ivory of Africa, the teas, spices, cotton, and jute of India, the teas of China, the cotton, timber, food supplies, and notions of America, the corn of Egypt and of Russia, the flour and wines of Hungary, the sugar, teak, and mahogany of the West Indies, the wools and preserved meats of the great Australian colonies, the

produce of the sister Isle, and the thousands of other things that form the imports of the two-mile-long Harbour of Glasgow, which, until a few years ago, was simply the river Clyde itself, lined on both sides with wharfs and quays, and carrying away to India, our colonies, and every foreign land, the varied products of this great City and of the whole South and West of Scotland, from the coal and iron of our mines to the finest productions of our looms and the most improved types of our varied machinery.

No wonder that the Harbour and Docks of Glasgow and the navigable part of the river Clyde excite the admiration and envy of the intelligent foreigner, when he learns that, 80 years ago, the quayage of the Harbour was only 382 yards long, the area of the Harbour only 4 acres, the annual revenue of the Clyde Trust only £3,400, the Customs revenue £427, and the population of the City 77,385, and that in 1880 the length of the quayage was 8,422 yards, or 4 miles 1382 yards, the area of the Harbour 140 acres, the revenue £223,709, the Customs revenue £956,620, and the population computed at 578,156.

All honour to the shrewd, far-seeing men who not only conceived the grand idea of bringing the sea to Glasgow and making its Harbour in the heart of the City, but resolutely set about accomplishing these ends, and to their successors in office who have carried, and are still carrying on this great, this beneficent work, and that without, until this day, a single penny of Government aid.

What would Glasgow have been to-day but for this great enterprise?—a mere burgh about the size of Dumbarton, which probably would have become the chief seaport of the West of Scotland. There would have been none of those gigantic shipbuilding yards and marine engineering works, giving employment to thousands, which have made the Clyde famous throughout the whole world. There might possibly have been a "Comet," drawing 4 feet of water, but there could have been no "Iona," no "Columba," no "Lord of the Isles," no "Livadia," with its 153 feet beam, no "Servia," 530 feet long; and none of those other floating palaces, those marvels

of construction, the models of many of which enrich and adorn our naval and marine engineering exhibition, could have been built on its banks: its shallow waters would have floated nothing of a deeper draft than a fishing smack.

The deepening and widening of the Clyde have increased the value of the lands on its sides through Glasgow and seaward a hundred-fold, created the Burghs of Govan, Partick, and the various other Burghs which environ Glasgow, given wealth to thousands, and the means of life to hundreds of thousands; and what has been the total expenditure up to 30th June, 1880?—only £8,786,128, of which £2,306,766 has been paid for interest on borrowed money.

I will now proceed to describe the steps taken and the works of improvement undertaken, resulting in the Harbour of Glasgow and the Clyde Navigation of to-day, merely mentioning, to localize the river, that it rises in the South of Lanarkshire from the same hill-ranges, on the confines of Lanarkshire and Dumfriesshire, near Moffat, that gives birth to the rivers Tweed and Annan—hence the saying—

> "The Tweed, the Annan, and the Clyde,
> All rise from one hillside."

It is 98 miles long, drains an area of 945 square miles, and discharges into the Atlantic Ocean, its ordinary rate of discharge being 48,000 cubic feet per minute.

In 1566 the first crude attempt was made to improve the river by detachments of the inhabitants of Glasgow, Renfrew, and Dumbarton endeavouring to open up a formidable sandbank at Dumbuck, above Dumbarton, at which they laboured for several weeks, residing, during the time, in temporary huts, built on the river banks, near the scene of their operations. It is presumed that similar attempts were made for a series of years, but apparently without much success, as for several years prior to 1658 the shipping port of Glasgow was Irvine, in Ayrshire. As the passage of lighters from that distant place was tedious, and land carriage expensive, the Magistrates of Glasgow in that year made overtures to the Magistrates of Dumbarton for the purchase of ground for an

extensive harbour there, which the latter declined to entertain, on the ground—"that the great influx of mariners and others would raise the price of provisions to the inhabitants." Disappointed in this project, the Magistrates of Glasgow turned their attention to the opposite side of the river, and, in 1662, purchased 13 acres of ground, on which they laid out the town of Port-Glasgow, built harbours, and constructed the first graving-dock in Scotland. Still desirous to have accommodation at Glasgow, they, in 1688, built a quay at the Broomielaw, at the cost of £1,666 13s. 4d.; but, even in 1740, little had been done in deepening the river, as the following Minute of Council, dated 8th May, 1740, will show:—"Which day, &c., the Councill agree that a tryal be made this season of deepening the river below the Broomielaw, and remit to the Magistrates to cause do the same, and go the length of £100 sterling of charges thereupon, and to cause build a flatt-bottomed boat, to carry off the sand and chingle from the banks."

The conviction seems to have grown stronger year after year in the minds of the Magistrates that the progress and prosperity of the City depended very much on the improvement of the river; and, in 1755, they set about it in earnest by employing Smeaton, the eminent engineer. His first report, dated 3rd September, 1755, contains much interesting and curious information. In it he notes that, of the twelve different shoals between Glasgow and Renfrew, "the two shoalest places" were at Pointhouse Ford, now the western boundary of the Harbour of Glasgow, where the river was 1 ft. 3 in. deep at low-water, and 3 ft. 8 in. deep at high-water; and at Hirst, now within the Harbour, where the depth was 1 ft. 6 in. at low-water, and 3 ft. 3 in. at high-water. There is now 14 ft. at low-water, and 24 ft. at high-water, at each of those places. He mentions that ordinary neaps were "sensible" at Glasgow, and so little appreciation had he of the future of the river as a navigation that he recommended that a lock and dam should be constructed at Marlin Ford, 4 miles below Glasgow Bridge, in order to secure 4 ft. 6 in. of water at all times up to the quay at

Glasgow, and he gives at great length his reasons for the recommendation. He proposed that the lock should be "18 ft. in the clear, and to take in a vessel of 70 ft. long, or to let pass a sloop or brig of above 100 tons, when there is water in the river to admit it."

Acting on Smeaton's advice, the first Act of Parliament, passed in 1759, was applied for. The preamble is instructive—"Whereas, the river Clyde from Dumbuck to the Bridge of Glasgow is so very shallow in several parts thereof that boats, lighters, barges, or other vessels cannot pass to and from the City of Glasgow except it be in the time of flood or high-water at spring-tides; and if the same was cleansed and deepened, and the navigation thereof made more commodious, by a lock or dam over the same, it would be a great advantage to the trade and manufactures of the city and parts adjacent and to the public in general." By this Act power was given to the Magistrates and City Council of Glasgow for the time being "to cleanse, scour, straighten, enlarge, and improve the said river Clyde from Dumbuck Ford to the Bridge of Glasgow, and to dig, cut, deepen the same, or any part thereof, and to cut, remove, take, and carry away all trees, roots of trees, sand or gravel beds, and all other impediments whatsoever which may any ways hinder or obstruct the said navigation; and to build, erect, and make in, over, or on the said river, or the lands adjoining to or near the same, or any of them, such and so many locks, wears, pens, dams, and cuts, trenches, and other works as to the said Magistrates and Council, and their successors in office, shall appear necessary or convenient for the promoting the said navigation, &c., &c. Provided always, that no lock or dam in, over, or upon the said river Clyde be built, erected, or made by the authority of this Act any lower down the said river than the lowermost part of a place therein called *Merlin-ford*, and that no dam shall exceed the height of 7 feet." It also empowered them to charge certain duties for defraying the expenses of carrying on the said works, and certain tolls, lock and keelage duties —payment of which were, however, only to commence "from

the time that the said lock or locks shall be erected and rendered passable, and not sooner."

Fortunately for Glasgow, no lock and dam were constructed. Nothing seems to have been done until 1768, when Mr. John Golborne, of Chester, visited the Clyde, and inaugurated the system of contracting the river by the construction of rubble jetties, and the removal of the gravel shoals by dredging or ploughing, which effected the first marked improvement of the navigation. Mr. Golborne, in his first Report, gives the depth at Hirst Ford as only 1 ft., and goes on to say:—

"The river Clyde is at present in a state of nature, and, for want of due attention, has been suffered to expand too much; for the sides in most places being much softer than the bottom, the current has operated there, because it could not penetrate the bed of the river, and has, by those means, gained in breadth what is wanting in depth.

"I shall proceed on those principles of assisting nature when she cannot do her own work, by removing the stones and hard gravel from the bottom of the river where it is shallow, and by contracting the channel where it is worn too wide; for quantities of sand brought down by the spates form banks in the channel, to the great detriment of the navigation. The first and grand obstacle is Dumbuck Ford (12 miles below Glasgow Bridge), where, the river dividing itself into two channels, the reflowing current is greatly weakened, and the bottom, being covered with a crust of hard gravel, cannot be worn down to a proper depth; but if a jetty were extended over the south channel, to confine the current, and the hard crust of gravel removed by dredging, the reflowing current would then act with greater force, and soon grind down a deep and capacious channel.

"By these means, easy and simple in themselves, without laying a restraint on nature, I humbly conceive that the river Clyde may be deepened so as to have 4 feet, or perhaps 5 feet depth up to the Broomielaw at low-water."

Further on he says: "When the river is confined to a proper breadth by jetties, the intermediate spaces will be filled up with sand carried down by spates and the fitts

brought by the tides, and become firm land." And he concludes this part of his Report by giving the following estimate of the expense, which, from its moderate character, deserves to be put on record:—

"An Estimate of the Expense of Improving the Navigation of the River Clyde.

| | |
|---|---|
| "To contracting the River with jetties, being eight miles, at £400 per mile, | £3,200 |
| To extending a jetty from Longoch Point over the south channel, | 1,260 |
| To contracting the channel at Kilpatrick Sands, | 1,000 |
| To dredging and deepening Dumbuck Ford, | 500 |
| To dredging and deepening the other fords, | 1,000 |
| To building three sets of ponts to carry stones, at £80 each, | 240 |
| To 20 per cent. on the whole, for unforeseen events, utensils, and engines, | 1,440 |
| Total, | £8,640" |

In 1769, James Watt, by the desire of the Magistrates of Glasgow, examined the declivity of the bed of the river Clyde from the Broomielaw Quay to Dumbuck Ford, below Bowling, according to Mr. Golborne's directions, and made a Report of the depth at low-water of the river at numerous places between Glasgow and Dumbuck Ford. At Hirst Ford, Harbour of Glasgow, he found the depth 14 inches, and at Dumbuck Ford, 2 feet.

The second Act was obtained in 1770, and the works stipulated for were clearly on the lines laid down in Golborne's able Report, as the preamble shows:—"Whereas, since the passing of the Act made in the 32nd year of the reign of his late majesty King George the Second, the said Magistrates and Council have caused a more accurate survey of the said river Clyde to be taken, and are now advised that by contracting the channel of the said river Clyde, and building and erecting jetties, banks, walls, works, and fences in and upon the said river, and dredging the same in proper places between the lower end of *Dumbuck Ford* and the Bridge of

Glasgow, the said river Clyde may be further deepened, and the navigation thereof more effectually improved, than by any lock or dam, and so as there shall be seven feet water in every part of the said river at neap-tides:

"And whereas by the said Act, the levying the rates and duties thereby granted stand suspended until the lock or locks thereby authorized shall be erected and made passable, and that this suspension of the collecting the said rates and duties which by this present Act are intended to remain and continue, will greatly retard the improving of the navigation of the said river; and that it is necessary a new mode or plan for levying and collecting the rates and duties be established, and a proper consideration granted to the said Magistrates and Council and their successors, in consideration of the great labour they must be at, and of the risque their common stock must run, in improving the navigation of the said river." The Act repealed the suspension of the collection of the rates and duties, and empowers the Magistrates to demand the rates granted by the first Act, and "to make and keep the said river Clyde navigable from the lower end of *Dumbuck Ford* to the Bridge of Glasgow aforesaid, so as there may be at least seven feet of water at neap tides in every part of the said river within the bounds aforesaid for ships, vessels, barges, and lighters to come and go, to and from the said City of Glasgow, and for that end to alter, direct, and make, or cause to be altered, directed, and made, the channel of the said river through any land, soil, or ground (part of the present bed of the said river) between the lower end of Dumbuck Ford and the Bridge of Glasgow aforesaid, and to make, set up, and erect on both sides of the said river such and so many jettees, banks, walls, sluices, works, and fences for making, securing, continuing, and maintaining the channel of the said river within proper bounds, for the use of the said navigation, as to the said Magistrates and Council, and their successors in office, shall seem proper and convenient, and for that purpose to cleanse, scour, deepen, and enlarge, or straighten or confine the said river and channel thereof, or any part or parts of the same, within the limits

aforesaid, and to dig or cut the soil, ground, or banks of the said river, and soil, sand, and gravel in the bed thereof, and to lay the same upon the most convenient banks of the said river and to plant the banks on each side of the said river within the bounds aforesaid with willows, or other shrubs, for the safety or preservation of the said banks, and for preventing the same from being hurt or carried away by the said river."

In 1773, Mr. Golborne took a contract to make Dumbuck Ford 6 ft. deep and 300 feet wide, at low-water, for £2,300; and on the 19th September, 1775, the Town Council—on the recommendation of the merchants—gave him £1,500 for deepening the river 10 inches more than he was bound to do by his contract, presented him with a silver cup, and gave his son £100.

In 1781, thirteen years after his first visit, Mr. Golborne again inspected the river at the request of the Magistrates, who, he says in his Report, were "desirous to know if a greater depth of water could be brought to the Broomielaw Quay, so as to receive vessels trading to England and Ireland;" and he reports that it gave him "great pleasure and satisfaction to find the general work in such good order and condition, and that the spaces between many of the jetties were filled up and covered with grass, to the great emolument of the proprietors and advantage of the river." And as the result of deepening Dumbuck Ford, he says:—"It gave me great pleasure to observe the channel at Dumbuck has considerably increased its depth since I removed the ford," and that, "on sounding it with the Magistrates, on the 8th day of August, 1781, at low-water, we had the pleasure to find no less than 14 ft.; for the jetty which I had carried over the south channel turned the current so effectually down the north channel, and the machines which I have used having cut through the stratum of clay into the sand, it was in many places from 20 ft. to 22 ft. deep."

Rennie followed Golborne, and, in 1799, recommended the shortening of some of the jetties, the lengthening of others, and the construction of new ones, "so as to direct the channel

in its proper course with the least obstruction to the water;" also the building of low rubble walls from point to point of the jetties, so as to render the channel uniform, and prevent the accumulation of shoals which he found had taken place between the jetties. Upwards of 200 jetties, varying in length from 50 feet to 550 feet, were erected between Glasgow Bridge and Bowling. These, while they effected a considerable deepening of the navigation, did, as Mr. Golborne expected, reclaim land to the proprietors, from the alveus of the river. Much of this land has since been purchased back, at great cost, for the subsequent widening and other improvements of the navigation.

The next recorded Report I can find bearing on the improvement of the river is dated Glasgow, 24th May, 1806, and is made by Thomas Telford.

He arranges his opinions under three heads—

1. The leading or bringing up a greater quantity of tide water.

2. The advantages to be derived from having a tracking or towing path on a part of the river.

3. Forming a Harbour at the Broomielaw.

Under the first head, he says:—"That, in order to obtain a greater quantity of tide water in the upper part of the river, the general principle is, to reduce the bed of the river to that form which shall afford the most direct course, oppose the fewest obstacles, and render the friction the least possible in regard to the section of the flowing water." He expresses the opinion that the "projecting jetties from each shore, for a considerable way into the river, is a very imperfect and improper means of attaining the object in view," and he recommends, for the purpose of bringing the river "into the most perfect form," the completing of the parallel dykes begun on the recommendation of Rennie, and the bringing of the river to an uniform width. Mr. Telford notes, as an

interesting circumstance, that "on the 14th February last, Mr. Archd. Wilkie, master of the 'Harmony' of Liverpool, then lying at the Broomielaw, informed me that he came up with ordinary spring-tide, drawing 8 feet 6 inches of water." He adds that this was a vessel of 120 tons burthen.

Under the second head, he says—"I find that, in navigating the river, vessels can come as far as Renfrew, with light winds; but the plantations near to Elderslie, by taking off the winds, frequently check the course of the navigation by leaving the vessels becalmed," and recommends, "that to render the navigation uniform and expeditious, a path should be completed, and horses applied to tracking this district." A towing path, 20 feet wide, was accordingly constructed on the south side of the river, all the way from Glasgow to Renfrew—a distance of 5 miles—and it continued to be much used until the advent of the steam-boat rendered its use for that purpose unnecessary. It now forms a valuable right-of-way to the public for foot-passenger traffic.

Under the third head—forming a Harbour at the Broomielaw—Telford disapproves of the extension of the then existing and only accommodation for vessels loading and discharging, namely, the quays along the river; and recommends the conversion of "a portion of the present bed of the river into a wet dock," and the making of a new channel to the southward. This advice was not followed; but instead, as the traffic increased, quays were extended along both sides of the river.

In 1807, in an exhaustive report, Rennie gave the widths he proposed the river to be—

| | | | |
|---|---|---|---|
| At Dumbarton Castle, - - - - | 696 ft. | It is now | 1,000 ft. |
| At west end of Bowling Bay, - - | 504 ,, | ,, | 400 ,, |
| At entrance to Forth and Clyde Canal, | 440 ,, | ,, | 590 ,, |
| At mouth of river Cart, - - - | 288 ,, | ,, | 500 ,, |
| Just above river Cart, - - - | 240 ,, | ,, | 500 ,, |
| At Renfrew Ferry, - - - - | 230 ,, | ,, | 410 ,, |
| Just below mouth of river Kelvin, which is now the lower boundary of the Harbour of Glasgow, - | 180 ,, | ,, | 370 ,, |
| In the Harbour, - - - - | 135½ ,, | ,, | 450 ,, |

Following up these Reports the third Act was obtained in 1809. By it power was given to deepen the river "till such time as the said river is at least nine feet deep at neap-tides in every part thereof between the Bridge of Glasgow and the Castle of Dumbarton," and the Lord Provost, Magistrates, and Council of the City of Glasgow for the time being, and their successors in office, were constituted Trustees.

The fourth Act was obtained in 1825. By it power was given to deepen the river between the Bridge of Glasgow and Port-Glasgow, "till such time as the said river is at least thirteen feet deep;" and "five other persons interested in the trade and navigation of the river and Frith of Clyde," whom the Magistrates and Council were authorised to appoint, were added to the Trustees.

From 1807 till the end of 1835, when Mr. Walker was appointed Engineer, deepening, widening, and straightening seem to have been continuously carried on; and in his first Report to the Clyde Trustees, dated February, 1836, he states that "there is now at the Broomielaw from 7 ft. to 8 ft. at low-water, while the lift of a neap-tide at Glasgow Bridge—which was only sensible in 1755—is 4 ft., and of a spring-tide, 7 ft. or 8 ft., making 12 ft. depth at high-water of a neap, and 15 ft. of a spring-tide; so that the river which, by artificial means, was to be rendered capable of taking craft of about 30 tons or 40 tons to Glasgow, has, by what Golborne calls 'assisting nature,' been rendered capable of floating vessels nearly ten times the burthen."

In 1837, Mr. J. Scott-Russell, at the instance of Sir Thomas Brisbane, Bart.—then President of the Royal Society of Edinburgh, and formerly President of the British Association for the Advancement of Science—and with the cooperation of the Clyde Trustees, spent several weeks in carrying out a most minute and elaborate series of observations on the tides of the Firth of Clyde, and furnished the latter body with a valuable Report, not only giving a table of tides, but also his opinion on the future improvement of the river. At that date spring-tides rose and fell about 11 ft. at

Port-Glasgow, and about 7 ft. at Glasgow. The tides now rise about the same at Port-Glasgow, but at Glasgow, springs rise 10½ ft., and neaps rise 9¼ ft. Then the time of high-water was 1 hr. 23 mins. later at Glasgow than at Port-Glasgow, now it is only 1 hr. 5 mins. In the beginning of the present century it was 3 hrs. later at Glasgow than at Port-Glasgow. In his Report, Mr. Scott-Russell predicted that if the depth of the river was increased sufficiently, high-water would be obtained at Glasgow within an hour after it reached Port-Glasgow; and his prediction has at length been all but fulfilled. The time of low-water at Glasgow is at present 1 hr. 40 mins. later than at Port-Glasgow. In the Harbour of Glasgow the tide flows for about 5 hrs. 40 mins., and ebbs for about 6 hrs. 50 mins. At Port-Glasgow it flows for about 6 hrs. 15 mins., and ebbs for about 6 hrs. 2 mins.

In November, 1839, parliamentary plans, prepared by Mr. Walker, were deposited, which dealt with the whole river under the jurisdiction of the Trustees, and on which defining lines for both sides of the river were laid down. These lines were approved of, and an Act to carry out the work in accordance therewith was passed by Parliament in 1840; and upon them—with very slight modifications at one or two places—the improvements of the river have since been carried out, Acts for such minor improvements having been obtained in 1857 and 1873.

Notwithstanding the great improvements effected previously to the passing of that Act, the parliamentary plans of 1839 show that, even so recently as then, the width of the river above Napier's Dock, in the Harbour of Glasgow, was only 168 ft. It is now 410 ft., and vessels of 3,000 tons burthen can float where, at that time, stood one of the largest cotton-mills then in the city.

| | | | |
|---|---|---|---|
| At Napier's Dock the width of the river, in 1840, was - - - - | 150 ft. | It is now | 490 ft. |
| At Finnieston Quay, in 1840, it was - | 160 ,, | ,, | 400 ,, |
| At Renfrew, in 1800, it was - - | 340 ,, | | |
| ,, in 1849, it was - - | 245 ,, | ,, | 410 ,, |
| At mouth of river Cart, in 1800, it was | 800 ,, | | |
| ,, ,, in 1840, it was | 275 ,, | ,, | 500 ,, |

What have been the means by which these important works of deepening, widening, and straightening, have been carried out? may well be asked. My reply is—Chiefly by dredging.

Narrowing the channel by jetties, and so causing scour, as recommended by Golborne, as already narrated, was among the first steps adopted—even ploughing and harrowing were had recourse to.

Where the sand banks in the river were bare at low-water, common land ploughs, wrought by horses, were called into use, the object being to break up the banks, so that the current might carry the sand away.

Another description of plough was much used. It consisted of a front plate of iron about 3 feet 6 inches long by 16 inches deep, with two timber sides about 5 feet long, 16 inches deep at the front, where they were firmly fixed to the iron plate, and tapered to about 10 inches at the back, where they were kept parallel with the front by an iron bar "kneed down" at the ends and fastened to the sides. When this plough was employed for the removal of gravel banks, the front plate was armed with four iron prongs, which projected about 8 inches or 9 inches below the bottom edge of the plate, and it was then called a "porcupine plough." A modification of this description of plough was also used. It was smaller in size, with iron sides, and had prongs projecting beyond both edges of the front plate so as to be reversible. It was so hung that the one side took a deeper hold than the other. The ploughs were fitted up with sling-chains at each end, and were wrought in pairs by hand capstans, two of which were placed on the river bank and two on a punt moored in the river, on the opposite side of the bank to be removed. One set of men on shore hauled the ploughs alternately through the bank towards them with their load of sand or gravel, which was removed at low-water on to the adjoining land, and a set of men on the punt drew the empty ploughs alternately back for a fresh hold.

Harrowing, also, was had recourse to. Taking advantage of freshes in the river, a harrow was attached by tackle to

the stern of a tug steamer, which set off with the tide, tearing up the bottom as far as requisite. The harrow was then lifted, and the tug steamed back against the tide, and, again dropping the harrow, repeated the operation.

Dredgers, with small buckets on a ladder, wrought by hand and by horses, followed the plough and harrow, and in 1824 the first steam dredger was started. It dredged only to 10 feet 6 inches; two years afterwards it was altered to dredge to 14 feet; now several of the dredgers employed can work to nearly 30 feet.

It is undoubtedly to the application of steam power to dredgers, and to the adoption of steam hopper barges—a French invention, I believe—for carrying away the dredged material to the sea that the rapid enlargement of the river and harbour in recent years are due; but for the introduction of the latter, it would have been well-nigh impossible to have disposed of the enormous quantity which is now yearly lifted.

The difficulty, however, of making reasonable arrangements with landowners for permission to deposit dredgings on the alveus or foreshores, and on the low-lying land adjoining, and the great cost of doing so—when the landowners, for valuable considerations, in the shape of rent, or the acquisition by them of the land reclaimed, gave permission—were the considerations which led the Trustees, in 1862, to adopt steam hopper barges for the purpose of conveying the dredgings to sea, and the Clyde Trustees now possess a fleet of eighteen of these vessels and five steam dredgers, which, in the year ending 30th June, 1878, lifted and disposed of 1,180,000 cubic yards of material, engine hours of dredgers 10,600, at the cost of £31,210 14s. 10d., or 6·35 pence per cubic yard; in the year ending 30th June, 1879, 1,502,696 cubic yards, engine hours of dredgers 10,910, at the cost of £36,732 6s. 8d., or 5·87 pence per yard; and in the year ending 30th June, 1880, 1,392,604 cubic yards, engine hours of dredgers 12,019, at the cost of £31,514 15s. 0d., or 5·43 pence per cubic yard; while the quantity dredged during the

last thirty-six years, viz., since 30th June, 1844, being the farthest back date that the statistics reach, is the large quantity of 23,606,382 cubic yards, and the total engine hours of dredgers 396,803, the quantity lifted for year ending 30th June, 1845, being only 233,944 cubic yards in 9,200 engine hours of dredgers.

The available depth of channel, which in 1839 was only 15 feet at high-water, is now 24 feet, and it is an interesting fact that the bed of the river is now as deep at Glasgow as at Port-Glasgow, and that it is virtually level throughout.

| | | | |
|---|---|---|---|
| The money paid for land for the enlargement of the river amounts to - - - - - - | £177,666 | 0 | 0 |
| The construction of works on the river has cost - - - - | 416,111 | 0 | 0 |
| And for dredging plant, and its repair, fully - - - - - - | 600,000 | 0 | 0 |

has been spent.

The improvement of the Clyde has destroyed one industry which once flourished on its banks—salmon-fishing, as a trade, above Dumbarton Castle, is extinct. The rights of salmon-fishing in the river were carefully protected in the earlier Acts of Parliament; and fishing stations were numerous, and of much value—one station, with its hut, being within the precincts of the Harbour, and persons are still living who have seen salmon landed from this station—but the "whir" of the paddle, the "churn" of the screw, and, above all, the sewage from the vast population in the area which the river drains, together with the deleterious liquid refuse from numerous manufactories of all kinds, have driven away that much-prized fish.

Even at the present time the Clyde Trustees pay upwards of £200 annually to the Burgh of Renfrew for damage to their salmon-fishings. The fishing rights of this royal burgh were very extensive, extending on the south side of the river from

Marlin Ford, 4 miles below Glasgow Bridge, to the Cloch Stane, about 6 miles below Greenock, and 27 miles below Glasgow.

On the other hand, the straightening, widening, and deepening of the river, from Glasgow seaward, has put an end for ever to the serious inundating of the low-lying portions of the City, which was of frequent occurrence up to the end of the fourth decade of the present century, by the river overflowing its banks; and Rennie reported very fully on the subject in 1799 and 1807, and Walker so lately as 1836. Thanks to the operations of the Clyde Trustees, boating in Jamaica Street, St. Enoch Square, and Stockwell Street, is now a thing of the past, the last time the river was over the Quays in the Harbour having been in 1856.

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## Beacons, Buoys, and Lighthouses.

The deep water channel below Dumbarton Castle is carefully defined by beacons and buoys, and in recent years the practice of navigating the river during the night having much increased, the additional facilities of lighthouses and cast-iron light-towers have been provided.

Three light-towers on the banks above Bowling mark bends in the course of the river; about a mile below Bowling a lighthouse has long existed on the south side of the deep-water channel; a lightship, on the same side, sheds its welcome rays along the channel in the estuary about a mile below Dumbarton Castle; and the north side of the channel, a short distance above Port-Glasgow, is marked by Cardross Lighthouse. All these are maintained by the Clyde Trustees.

Now about the Harbour. While the enlarging of the river was going unremittingly on during all these years, the extension of the Harbour, for which all this expenditure was

being incurred, was keeping pace, as will be seen in the following table:—

| Date. | Length of Quays. | Water Area of Harbour. | Depth of Water in Harbour at High Water. | Vessels arrived. Maximum Draught. | Vessels arrived. Total Registered Tonnage. | Goods Inward and Outward. Total Tonnage. | Total Revenue of Clyde Trust. | Customs Revenue Collected at Glasgow. | Population of City of Glasgow. |
|---|---|---|---|---|---|---|---|---|---|
| | yds. | acres. | ft. in. | ft. in. | tons. | tons. | £ s. d. | £ s. d. | |
| 1801 | 382 | 4 | ... | ... | ... | ... | 3,400 10 9 | 427 17 7¾ | 77,385 |
| 1811 | 697 | 7 | ... | ... | ... | ... | 4,755 3 8 | 3,124 2 4½ | 100,749 |
| 1821 | 697 | 7 | ... | ... | ... | ... | 8,070 2 2 | 16,147 17 7 | 147,043 |
| 1831 | 1,543 | 14 | 14·6 | 14·0 | 732,327 | ... | 18,932 0 7 | 68,741 5 9 | 202,426 |
| 1841 | 1,973 | 23 | 18·6 | 17·0 | 1,142,373 | ... | 49,665 15 7 | 526,100 0 11 | 255,650 |
| 1851 | 3,591 | 51 | 20·0 | 18·0 | 1,446,606 | 1,023,216 | 68,875 4 9 | 675,044 15 10 | 329,096 |
| 1861 | 4,376 | 70 | 22·0 | 20·0 | 1,504,220 | 1,366,327 | 105,768 11 0 | 924,445 10 0 | 395,503 |
| 1871 | 5,604 | 75½ | 23·0 | 22·0 | 2,049,708 | 1,986,194 | 164,188 18 7 | 850,256 9 7 | 477,710 |
| 1880[1] | 8,422 | 140 | 24·6 | 23·0 | 2,944,051 | 2,653,088 | 223,709 0 8 | 954,620 15 5 | 578,156[2] |

[1] The quayage area in harbour in use in 1880 was 52 acres, and the area covered with sheds 18 acres.

[2] Computed.

Citizens of Glasgow, still in active life, have waded across the Harbour, below Glasgow Bridge, and, as boys, have crept through the circular openings between the arches of the old bridge, and it used to be a favourite amusement with boys on summer evenings to throw stones across the river opposite where the General Terminus Quay now is.

The total length of quayage in 1800 was, as I have already said, 382 lineal yards. It extended from Glasgow Bridge to opposite the foot of York Street. All below that, on the north side, was green bank, and all the south side was the same. The width of the river, from immediately below the Bridge —all the length of the quay—was only 145 feet, and a friend informed me a few days ago that he quite remembers the great bank opposite the quay, belonging to the Trades' House, and of the high stakes or round piles at the water edge, near the Bridge, on the bank, to which the vessels lying at the quay used to be moored when the river was in spate, to keep them from being carried away down the river, and probably stranded on the banks below. It was not till 1837 that the first length of quay on the south side, and next the Bridge, was finished, and the width of the river increased there to fully 400 feet—the land having been bought from the Trades' House in 1826.

I need not weary you with details of the quay walls and wharfs which, from 1800 till now, have been erected, but as within the last ten years a novel description of foundation was adopted in place of the old system of wooden piles— first in the construction of Plantation Quay on brick cylinders, and subsequently in the quayage of Queen's Dock on concrete cylinders—it may suffice that, in describing the Queen's Dock, I explain this new system of foundations as carried out in this important work.

Although docks were, at the instance of the Magistrates, reported on and recommended by Telford in 1806, and in 1819; by Rennie in 1806, and in 1807; by Clark in 1824; by Hartley in 1834; by Logan in 1835; by Walker in 1836, in 1849, in 1853, and in 1855; by Bremner in 1849; and by Ure in 1854, and in 1855; and although Acts of Parliament were obtained for their construction in 1840, and in 1846, it was not until 1867 that the first dock constructed at Glasgow was opened. It is a tidal dock, having $5\frac{1}{3}$ acres of water space, and is surrounded with a timber wharf giving 830 lineal yards of quayage.

Thirty-five acres of ground for dock purposes at Stobcross,

Glasgow, were purchased by the Clyde Trustees so long ago as the year 1845, for carrying out the Dock Act of 1846. Until, however, within the last few years, the Trustees were able to obtain ground along both margins of the river Clyde for quay extension, and the river itself was water-space made to their hands free of cost, save for a little expenditure in dredging in front of the quays; and it was only when that ground was nearly all utilized for quayage that their attention was seriously turned to making docks out of dry land.

The dock originally proposed to be made at Stobcross, and designated until lately the "Stobcross Dock," was to consist of a tidal basin and a wet dock, having together 1,458 lineal yards of quay, 16 acres of quayage, and 17 acres of water-space.

In 1864 the Edinburgh and Glasgow Railway Company, now merged in the North British Railway Company, obtained an Act to make a railway from their Helensburgh Branch to the authorised Dock, with a station immediately on the north side thereof, and to make a branch to the Trustees' Tramways, for which an Act was obtained the same year, but no action was taken towards constructing either the railways or the tramways, and financial difficulties having occurred with the Railway Company, they proposed, in 1869, to apply to Parliament for permission to abandon the railways. The Trustees objected to this, and an agreement was come to whereby the Railway Company consented to proceed with the railways, and to remove their station further north to enable a larger dock to be constructed, as recommended by Mr. J. F. Bateman, C.E., and myself, in our joint Report to the Trustees, dated 21st September, 1869. And the Clyde Trustees agreed, subject to Parliamentary sanction, to contribute a loan of £150,000 towards the making of the railways. Acts were obtained in 1870 by the Railway Company for the removal of the site of the station, and by the Clyde Trustees for enlarged docks, and to carry out the agreement as to the money loan.

The Dock authorised by this Act and now constructed,

except the completion of the dredging-out, has a length of quayage—

| | | |
|---|---|---|
| Inside Dock, of - - - - | 3,334 lin. yards. | |
| Outside of Dock, - - - | 494 ,, yards. | |
| Total, - - | 3,828 ,, yards. | |
| or 2 miles 308 yards. | | |

The total water-space inside the Dock is $33\frac{3}{4}$ acres, and the area of quayage $27\frac{1}{2}$ acres.

It comprises three Basins—the North Basin, 1898 feet long by 270 feet wide; the South Basin, 1675 feet long by 230 feet wide, with a Quay between them 195 feet broad; and an Outer Basin, 695 feet wide, at its widest part, by 1000 feet long. The area of the Outer Basin is 13 acres, of the North Basin, $11\frac{3}{4}$ acres, and of the South Basin, 9 acres. The Dock is tidal, and is approached by an entrance 100 feet wide, which is crossed by a Swing-bridge constructed by Sir Wm. Armstrong & Co. There are four Coaling Cranes to lift 20 tons each, on the North Quay of Dock, all of which, together with the Swing-bridge—which is constructed to carry 60 tons of a rolling load on any part of its roadway—are wrought by hydraulic power.

Before proceeding with the construction of the Dock, it was necessary to learn, by boring, the character of the ground in which the walls were to be placed. 123 bores were put down for this purpose along the lines of the Quay walls, and it was ascertained that the strata was the worst possible in which to construct in the usual manner such works, consisting as it does—except at the north-west corner, where boulder clay was found—entirely of water-bearing gravel and sand interspersed with pockets of mud, and that to reach the rock would be out of the question.

Owing to the enormous quantity of water, the walls could not, except in the boulder clay, at any reasonable expenditure, have been constructed by excavating trenches to the required depth in the gravel and sand; concrete cylinders, which had been recommended to the favourable consideration of the Trustees by Mr. Bateman and myself in our Report already

alluded to, were adopted, and the first contract for the Dock, amounting to fully £160,000, was let in August, 1872. The first work, however, contracted for in connection with the Dock was the diversion of the Pointhouse Road from the river side to the north side of the Dock, which was let in July, 1871. The execution of this work, from the variety of strata it disclosed—ranging from boulder clay of the most tenacious character to the finest and sharpest of sand, much of which was used for glass-making—excited the liveliest interest among geologists.

The road extends from Stobcross Street to Sandyford Street, a length of 989 yards, is 55 feet wide; the average depth of cutting was 29½ feet, the greatest depth being 43½ feet. The total quantity of material removed in its construction was nearly 300,000 cubic yards, of which about a fourth was boulder clay, in the removal of which the immense powers of dynamite were utilized. The cost of the road, including land, amounted to about £45,000. It was opened for traffic in April, 1875.

The second and third contracts for the Dock, amounting to £40,000 and £121,500 respectively, were let in April, 1876, and the fourth contract, which completed the contracts for the Quay Walls, amounting to £206,600, in November, 1876. The first contract was completed in March, 1878, the second in May, 1878, the third in May, 1879, and the fourth on the 20th March, 1880, when the last copestone was formally laid by Lord Provost Collins, the Dock having been partially opened by Lord Provost Bain on the 18th September, 1877.

The North Quay Wall of the Dock, so far as constructed on boulder clay—and that is for about 1,297 feet of its whole length of 2,951 feet—is of the usual description, the only difference being that concrete founds, 2 feet 6 inches thick, were used in place of freestone blocks, and that rubble set in Portland cement concrete—a much superior mode of construction—were employed for the backing, instead of rubble built with ordinary mortar. Where the bottom consisted of strong, coarse gravel or rock, liquid concrete was substituted

for the solid concrete blocks, by which means all the holes and inequalities in the surface of the rock were thoroughly filled, and an even and fair surface obtained on which to commence the building of the wall.

All the other walls, except at two or three places where pockets of clay were encountered, when piling was adopted, as also the Seat for Swing-bridge, having to be built in quicksand or gravel, concrete cylinders were adopted.

The cylinders for carrying the Quay Walls are triune. They were made in rings 2 ft. 6 in. deep by 1 ft. 11 in. thick, in moveable wooden moulds on a platform. The concrete consisted of 5 of gravel, or broken stones and sharp sand, to 1 of Portland cement of the strongest description, mixed together by steam-power in a mixer designed for the purpose, water being added to bring the mass into a plastic state. To facilitate lifting, the rings were divided into three and four pieces alternately, so as to break bond when built into the cylinders. The dividing of the rings was very simply effected; malleable-iron division plates, $\frac{3}{8}$ths of an inch thick, were placed across the wooden moulds in the positions required, before the concrete was filled into them, the concrete was then put in, and well punned with hammers weighing 25 lbs., so as to secure homogeneity and a smooth surface. Twelve hours afterwards the division plates were withdrawn, and two days thereafter the wooden moulds, and in periods varying from nine days in the hot weather of summer to three weeks in the rains of winter, the rings were ready for removal and building. The contents of one ring complete was $10\frac{1}{2}$ cubic yards, and the weight 18 tons—the heaviest portion weighing about 6 tons.

The cylinders were each 11 rings, or 27 ft. 6 in. in height; the bottom ring, differing from the others, was called a "corbelled ring," because it was less in thickness at the bottom, to fit into a cast-iron shoe, and tapered inwards to the full thickness of 1 foot 11 inches. The shoe was 2 feet deep, of 1 inch metal, and of the same external size and shape as the rings; the under side of the bottom ring rested on a shelf in the shoe, 6 inches below the top edge of shoe. This

shelf was formed by an inner ring of cast-iron, 1 inch thick, projecting at the top 12 inches inwards from the inside of the outer side of shoe, and tapering outwards to the bottom of shoe, where it joined the outer ring, thus forming a cutting edge to the shoe—the wedge-shaped space between the outer and inner ring being filled up with concrete.

The shoe is only under the outward circumference of the "corbelled ring," the inner parts of the ring being unshod. The shoe weighed about 4 tons 10 cwts., and for convenience in placing in the trench was made in six parts.

In proceeding with the construction of the substructure, a trench was cut on the line of the Quay Wall; the bottom of this trench was about 12 inches below low-water level, where it was made 21 feet wide, the sides of trench sloping upwards with a batter of 1½ horizontal to 1 perpendicular, and the necessary staging was erected to carry the travelling cranes and digging apparatus. On the bottom of this trench the shoes were placed exactly in the line of the Quay Wall, the space between the outer and the inner rings of shoe was filled up with concrete, as already explained, the "corbelled ring" was placed on the shelf in the shoe, and bolted to it by thirteen 1¼-inch bolts, a malleable-iron ring, 5 inches by ½ inch thick, being sunk into the "corbelled ring" on the top, the places for this ring and for the bolts passing through the concrete ring having been made in the moulding of the latter. The remaining ten rings forming the cylinder were set one on the top of the other in Portland cement, in three and four pieces alternately, so as to break bond. The cylinders being triune, or in groups of three, were placed in the trench so as to dovetail into each other, one in front and two behind, and two in front and one behind alternately—the sides of the groups where they pressed against each other being flattened for a length of 5 feet, so as to ensure a good bearing.

On the completion of the building up of the rings forming one group of cylinders, the sand and gravel were dug out simultaneously from within each of the three cylinders, by means of excavators specially designed for that purpose. From

300 to 400 tons of cast-iron weights of the same shape as the rings were generally required to force each group of cylinders down to the required depth, which is 48 feet 6 inches below the cope level of Quay, the tops of the cylinders finishing about 9 inches below low-water level. The average rate of sinking was about 12 inches per hour. In good working sand as much as 3 feet per hour was, however, attained.

After the group had been sunk, it was cleaned out by means of the excavators to the level of the bottom of the shoe, and each cylinder was then filled to the top with Portland cement concrete, and on this foundation the Quay Wall was built.

The Walls are of concrete rubble, many of the stones weighing two to three tons each, faced with freestone ashlar in courses, ranging from 18 inches to 15 inches in thickness, the stones being not less than 4 feet long by 2 feet broad on the beds, and the headers not more than 10 feet apart centres.

The Cope is of granite, 3 feet 6 inches broad by 17 inches thick, in lengths of not less than 4 feet; and the mooring paals or bollards, which are 32 feet apart centres, are built into the wall immediately behind the cope.

To effectually close up the apertures formed by the joining of each two groups of cylinders, a timber choke-pile, 25 feet long by 9 inches square, was driven behind, angle ways, so that a sharp corner might bear hard against each of the cylinders.

The Swing-bridge across the entrance to the Dock rests on a foundation probably unique in the annals of swing-bridges—viz., on a group of concrete cylinders, 12 in number, 9 feet in external diameter, 29 feet in depth by 23 inches thick, resting on cast-iron shoes similar to those described for the Quay Wall foundations. The cylinders were sunk in the manner already described, and after they and the interstices between them were properly cleaned out, all the voids were filled to the top with concrete, choke-piles being driven where required. On the centre of the rectangular area, 36 feet 4 inches, by 27 feet 3 inches by 29 feet deep, thus formed, a stepped ashlar Pier, 16 feet square at the bottom and 10 feet square at the top, by 7 feet high, was erected, which carries

a block of granite 7 feet square, by 3 feet 6 inches deep, on which the centre lifting press rests. The Pier is surrounded by concrete rubble, the whole forming a mass of masonry 36 feet 6 inches, by 32 feet 6 inches, by 10 feet 6 inches high to level of floor of Bridge Press Chamber. The Centre Pier sustains a weight of 800 tons.

Considerable difficulty was experienced in securing stable foundations for the Hydraulic Rams for working the Bridge, and for the Capstans, and side walls of Bridge Pit, the ground being loose and insecure where these had to be placed. Single concrete cylinders placed apart and spanned between by brick arches overcame the difficulty.

The Bridge is 181 feet 6 inches long by 40 feet 6 inches wide, the length overhanging the centre of Centre Press and partly spanning the 100 feet opening, being 126 feet 6 inches. It and the Hydraulic Machinery have been in daily use since the 18th September, 1877, when the Dock was formally opened by the admission into it of the Anchor Line s.s. *Victoria*, 369½ feet long by 40 feet broad, 2,081 tons register, and by the special and gracious permission of Her Majesty Queen Victoria, named the Queen's Dock.

The Coaling Cranes are capable of lifting 20 tons. They are placed on stone seats, the granite tops of which are 8 feet above the level of the Quay, and 21 feet 6 inches square; the lifting chains have a sweep of 29 feet 9 inches, and when at right angles to the face of Quay they project 19 feet 9 inches beyond the water face of seat; the lifts of the chains are 20 feet.

In addition to their employment in the shipment of coals, they are also adapted to the loading and unloading of machinery up to their maximum lifting power.

The Sheds, so far as yet built, are 60 feet wide by 15 feet high to under side of run-beams, and 27 feet to ridge of roof; the back walls are of brick 19 inches thick, with freestone base course, cope, and door openings; the roofs are of iron, and the fronts are closed in their entire length with sliding gates of timber. The cost per lineal foot of Shed at present prices is £10 10s.

The cost of the Quay Walls per lineal yard, including the excavation for trench below level of cope, were, for

| | | | |
|---|---|---|---|
| CONTRACT No. 1. Let in August, 1872. | | | |
| Quay Wall, on Cylinders, - - - | £154 | 2 | 0 |
| Quay Wall, on Sheet and Bearing Piles, - | 144 | 8 | 0 |
| Ordinary Quay Wall, founded on Boulder Clay, - - - - - - | 116 | 5 | 0 |
| Quay Wall, on Piles and Concrete, substituted for Cylinders, - - - - - | 172 | 0 | 0 |
| CONTRACT No. 2. Let in April, 1876. | | | |
| Quay Wall, founded on Boulder Clay, - | 101 | 7 | 6 |
| CONTRACT No. 3. Let in April, 1876. | | | |
| Quay Wall, on Cylinders, - - - | 139 | 4 | 0 |
| CONTRACT No. 4. Let in November, 1876. | | | |
| Quay Wall, on Cylinders, - - - | 129 | 12 | 8 |
| Do. founded on Rock, - - | 101 | 6 | 8 |

The total cost of the Dock, when fully equipped, will approach £1,500,000.

The following particulars connected with the Dock may possibly be of some interest:—

| | | | |
|---|---|---|---|
| Excavation for Walls above formation level, | | 255,871 | Cub. Yds. |
| Excavation in Wall Trenches, - - - | | 494,764 | „ |
| Excavation in Sinking Cylinders, - - | | 126,407 | „ |
| Concrete in Cylinder Rings, - - - | | 1,800,203 | Cub. Ft. |
| Concrete filling of Cylinders, - - - | | 1,313,010 | „ |
| Gravel filling of Cylinders, - - - | | 99,495 | „ |
| Number of Cylinders—Triune, - - | 607 | | |
| Do. do. Twin, - - | 1 | | |
| Do. do. Single, - - | 20 | | |
| Total, - - - | | 628 | „ |

Total length of Cylinders, - 17,085 feet, or 3 miles 415 yards.

| | | |
|---|---|---|
| Ashlar Masonry, - - - - - - | 747,223 | Cub. Ft. |
| Rubble and Concrete Masonry, - - | 2,511,919 | „ |

The Quay Walls are founded as follows:—

| | | |
|---|---|---|
| Upon Concrete Cylinders, - - - - | 2,813 | Lin. Yds. |
| Upon Boulder Clay, - - - - - | $479\frac{2}{3}$ | „ |
| Upon Rock, - - - - - - | $210\frac{1}{3}$ | „ |
| Upon Hard Gravel, - - - - - | 122 | „ |
| Partly upon Rock and partly upon Boulder Clay overlying Rock, - | $12\frac{1}{2}$ | Lin. Yds. |
| Upon Timber Piling and Concrete, - | $56\frac{1}{2}$ | „ |
| Timber Wharf at entrance, - - | 134 | „ |
| Total, - - - - - | 3,828 | Lin. Yds. |
| | or 2 miles 308 yards. | |

The total quantity dredged in connection with the formation of the Dock up to 31st December, 1880, was 1,945,000 cubic yards.

The first of the ground acquired for the Dock was bought in 1843 at 6s. 6d. per square yard, and the last in 1872 at 35s. Since the latter date, ground in the immediate vicinity, but not so favourably situated, has changed hands at 65s. per yard.

Placed in close contiguity with the Dock, the large Crane and Crane Seat, on the Riverside Quay, Stobcross, deserve a passing reference. The Crane, which is chiefly of wrought-iron, was made by Messrs. James Taylor & Co., Birkenhead, and tested to 60 tons. It is a duplicate of the one on the South Quay of the Harbour, nearly opposite, erected in 1874; being composed chiefly of wrought-iron, the makers were able, most successfully, to combine lightness and elegance of form with ample strength, and, elevated high above the quay level, they are both conspicuous objects in the Harbour.

It is principally, however, with reference to the Seats on which they are placed that I desire to refer to them. A description of the Seat for the Crane at Stobcross will suffice for both. It is of novel construction, the strata on which it rests is quicksand, and it being impossible to found the substructure dry at the depth of at least 20 feet below low-water, necessary to permit of dredging to that depth in front so

as to float the large steamers, to engine which the Crane has been erected, an entirely new description of substructure was adopted, similar to the foundation for the Seat of the Swing-bridge.

The foundation on which the Seat rests consists of 24 concrete cylinders 9 feet in external diameter by 23 inches thick, placed each on a cast-iron shoe, and sunk till the shoes reach the depth of 50 feet below the level of the Quay. The cylinders are finished at 3 feet below low-water level, and are filled up with concrete of a weaker character than the cylinders, the spaces between these cylinders having been, after they were sunk, cleaned out and also filled up with concrete. On the top of the cylinders the Seat proper is placed. It consists of ashlar and concrete rubble masonry from 3 feet below low-water. The total height of the Seat above the top of the cylinders is 38 feet. Up to 9 feet above the Quay level it is perpendicular on all sides, and measures 44 feet by 38 feet. At that level it is reduced in size to 36 feet by 34 feet, and is stepped up on three sides to the top, which measures 32 feet square, and is 16 feet above the level of the Quay. The face of the Seat next the river is perpendicular for its whole height from top of cylinders, and is in line with the face of the Quay Wall. The estimated weight of the masonry in Seat above cylinders is 3,800 tons, and above level of washers of holding-down bolts 1,940 tons, and of Crane without load 150 tons. The Crane is supplied with one of Duckham's Hydrostatic Weighing Machines, which have been extensively used by the Trustees. The corners of Seat are of granite, as is also the cope, which is 30 inches thick.

The following are a few of the leading features of the Crane:—

| | Ft. | In. |
|---|---|---|
| 1. Height of top of seat above cope level of Quay, - - - - - - - | 16 | 0 |
| 2. Sweep of Crane, - - - - - | 48 | 0 |
| 3. Projection of chain pulleys, at point of jib beyond face of Seat, the jib being at right angles to Quay Wall, - - - | 32 | 1 |

| | | Ft. | In. |
|---|---|---|---|
| 4. | Height from cope of Quay Wall to centre of chain pulleys, - - - | 71 | 10 |
| 5. | Height from low-water level to centre of chain pulleys, - - - - - - | 90 | 10 |
| 6. | Height from level of cope of Quay Wall to underside of jib at face of Seat, the jib being at right angles to Quay Wall, | 24 | 9½ |
| 7. | Greatest height of lift from quay level to lower end of egg-shaped eye hook under pulley blocks at end of chain, - - | 58 | 9 |
| 8. | Greatest height with hydrostatic weighing machine attached to end of chain, - | 54 | 7 |
| 9. | Greatest depth at low-water in front, - | 20 | 0 |
| 10. | *Hoisting Engines*— | | |
| | Diameter of cylinders, - - - | 0 | 10 |
| | Length of stroke, - - - - | 1 | 4 |
| 11. | *Slewing Engines*— | | |
| | Diameter of cylinders, - - - | 0 | 8 |
| | Length of stroke, - - - - | 1 | 0 |
| 12. | *Rate of Lifting*— | | |
| | Slow purchase | | |
| | Load 60 tons, - - - per min. | 3 | 10 |
| | Quick purchase | | |
| | Load 10 tons, - - - per min. | 19 | 6 |
| 13. | *Rate of Slewing*— | | |
| | Load 10 tons | | |
| | Complete revolution, 2 min. 3 sec. | | |
| | Velocity per minute at point of suspension of load, - - - - | 147 | 4 |

The Crane makes a complete revolution with 60 tons in 2 minutes 20 seconds, or at a velocity of 129 ft. 6 ins. per minute at the point of suspension of load, and has a separate inhaul crab-winch wrought by hand, so that the heaviest load

can be adjusted to a hairbreadth in the place it is required to occupy. This is of great use to engineers while placing machinery on board of new steamers.

In addition to the Cranes already referred to, the Harbour is well equipped with other Cranes—there is a 50-ton, a 40-ton, a 30-ton, and numerous smaller steam cranes. The gross revenue from crane dues last year was £5,595, and the year before £6,930.

The only Public Graving Dock as yet on the Clyde above Port-Glasgow is the one at Govan, for which the Clyde Trustees obtained an Act in 1868. Its construction was commenced in March, 1869, and after much delay in execution it was opened in December, 1875.

It is 565 ft. in length within the caisson, 72 ft. wide at entrance, and has 22 ft. of water on cill at high-water of ordinary spring-tides, and ranks among the largest docks in the kingdom. An Act for another dock alongside it was obtained in 1873, but its construction is not yet begun.

In 1856, Messrs. Tod & M'Gregor, engineers and shipbuilders, had the enterprise to construct a graving dock—in connection with their extensive works at Meadowside, on the north bank of the Clyde and west bank of the Kelvin, now in possession of Messrs. W. & D. Henderson & Co.—500 ft. in length, with an entrance of 56 ft. wide. At Dumbarton there is another private dock, 300 ft. long, with an entrance 41 ft. wide. A graving dock, designed by James Watt, has existed at Port-Glasgow since 1762. It was recently lengthened to 310 ft.

The Port of Glasgow is fairly well supplied with Slip-docks—there are two at Kelvinhaugh Shipbuilding Yard, one at Pointhouse Shipbuilding Yard, and one at Meadowside Shipbuilding Yard, all in the hands of private firms, while the Clyde Trustees have one at their Dalmuir Works for the use of their Dredging plant, and there is one at Bowling.

A description of the Harbour would not be complete without a reference to the Ferries.

I do not know if it is correctly known when Ferry-boats commenced to ply across the Harbour, but they have now

become an important means of public accommodation, and the Clyde Trustees have now six Harbour Ferry Passenger Steamers, and two Passenger, Carriage, Cart and Horse Steamers for Govan Ferry. Three of the Harbour Steamers are also Floating Fire Engines, and have proved useful as such.

The Harbour Steamers are licensed to carry from 46 to 108 passengers. The first commenced to ply in December, 1865, previous to which all the ferrying was performed by row-boats. There are five Ferries across the Harbour, four of which are steam.

Steam was first applied to the Govan Ferry in 1867, when the first steamer was put on, superseding the boat wrought by a hand-wheel. This steamer is of 15 H.P., nominal, has a single cart and carriage way in the centre, accommodates three horses and carts and 50 passengers, or 200 passengers alone, and is wrought on one chain stretched across the river. The second steamer commenced working in 1875, it is 20 H.P., nominal, has two cart-ways, one on each side, the passengers being accommodated in the centre; it carries 8 horses and carts and 140 passengers, or 500 passengers alone, is wrought on two chains across the river, one on each side of the cart-way.

The Trustees have also a Row-boat Ferry across the mouth of the Kelvin, and one at Whiteinch, about a mile below the western limit of the Harbour.

The Ferries at Clyde Street, Stobcross, and Govan are open night and day, the other Harbour Ferries from 5 a.m. to 11 p.m.

The number of passengers conveyed across the river at the eight Ferries during the year ended 31st December, 1880, was 8,270,632, while the gross revenue derived therefrom was £14,774 17s. 9d.

The charge for crossing is one halfpenny, while tickets are issued, restricting the holders to certain hours of crossing, at one farthing; half-yearly tickets, entitling the holders to cross as often and at any time they choose, are issued at 20s. each.

The Vehicular traffic at Govan Ferry during the year 1880 was as follows:—

| | |
|---|---|
| Loaded Carts, - - - - - - | 14,568 |
| Empty Carts, - - - - - - | 16,361 |
| Loaded Lorries, - - - - - - | 5,356 |
| Empty Lorries, - - - - - - | 5,606 |
| Loaded Carriages, - - - - - | 393 |
| Empty Carriages, - - - - - | 532 |
| Loaded Cabs, - - - - - - | 1,648 |
| Empty Cabs, - - - - - - | 1,100 |
| Loaded Hurley Barrows, - - - - | 1,948 |
| Empty Hurley Barrows, - - - - | 1,192 |
| Loaded Wheel Barrows, - - - - | 191 |
| Empty Wheel Barrows, - - - - | 414 |
| Perambulators, - - - - - - | 851 |
| Horses, - - - - - - - | 4,084 |
| Cattle, - - - - - - - | 7 |
| Sheep, - - - - - - - | 44 |
| Lambs, - - - - - - - | 57 |

Gross Revenue from same, £737 3s.

The following items of total Expenditure up to 30th June, 1880, in connection with the Harbour, will show the magnitude of that part of the undertaking—

| | | | |
|---|---|---|---|
| Ferries, - - - - - - - | £135,372 | 0 | 0 |
| Ground-annuals and Feu-duties, - | 264,015 | 0 | 0 |
| Taxes, - - - - - - - | 118,797 | 0 | 0 |
| Land purchased for enlargement of Harbour, - - - - - | 975,782 | 0 | 0 |
| Construction of Harbour Works, - | 984,560 | 0 | 0 |
| Kingston Dock, Works, - - - | 97,337 | 0 | 0 |
| Graving Docks, Works, - - - | 140,126 | 0 | 0 |
| Queen's Dock, Works, - - - | 737,619 | 0 | 0 |

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## Bowling Harbour.

In 1768 an Act was passed for the construction of a navigable canal from the river Forth, near the mouth of the

river Carron, to the river Clyde, near Bowling, to be called the Forth and Clyde Navigation, and, in 1775, the canal was opened for traffic. Previous to 1846, the only connection of the canal with the Clyde was direct from the river by means of a lock, but in that year the proprietors of the navigation obtained parliamentary authority for the construction of an outer basin, or harbour, at Bowling Bay, and wharves or quays in connection therewith, with a lock to connect the proposed harbour with the canal, and the works were shortly afterwards executed. The area of the Canal Company's basin is about 3½ acres, having 390 lineal yards of quayage and wharfage inside the basin, and 196 lineal yards facing the river. The Clyde Trustees, about the same time that the Canal Company formed this basin, erected a wharf immediately below its entrance—on the line of the training dyke inclosing Bowling Bay—for the use of vessels of deep draught, while waiting the flowing of the tide. In 1856 they raised the training dyke to about 8 ft. above the level of high-water, and closed in the lower end of the bay with a dyke of the same height; and greatly deepened the bay inside. A tidal basin of 8½ acres was thus formed, which every winter is full of river steamers and other craft laid up for the season.

In addition to the Acts of Parliament already referred to, the Trustees have had the following Acts passed in their behalf:—

1854.—Money Act.
1858.—Consolidation Act.
1864.—Harbour Tramways.
1868.—Graving Dock.
1873.—Graving Dock, Quays, Wharfs, &c.
1878.—Stobcross Ferry.

By the Consolidation Act of 1858 the constitution of the Trust was materially altered. Previous to the passing of that Act the management of the harbour and the river was virtually in the hands of the Magistrates and Town Council of Glasgow. By that Act, which is still in force, the number of

Trustees was fixed at twenty-five, one being the Lord Provost of Glasgow, nine Town Councillors, and the remaining fifteen representatives of the shipping, mercantile, and trading interests of Glasgow, of whom two must be chosen by the Chamber of Commerce of Glasgow, two by the matriculated members of the Merchants' House of Glasgow, two by the members of the Trades' House of Glasgow, and nine by the shipowners and ratepayers. The qualification of the Trustees to be elected by the shipowners and ratepayers is ownership to the extent of at least 250 tons in any vessel, or vessels, registered at the port of Glasgow, or payment of rates to the extent of £25, or upwards, per annum; and of electors, ownership to the extent of at least 100 tons, or payment of £10, or upwards, of rates per annum.

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## Introduction of Steam Propulsion and Progress of the Shipping Trade on the River.

The first steamer built on the Clyde was the *Comet*, constructed in 1811-12 for Henry Bell, of Helensburgh, and from his designs, by John Wood, shipbuilder, Port-Glasgow, and engined by John Robertson, of Glasgow, at the cost of £192. It had 40 feet length of keel, and 12 feet beam; its engines were 4 H.P., its draught of water 4 feet, and it was capable of carrying 40 passengers fore and aft. It plied between Glasgow, Greenock, and Helensburgh, sailing from Glasgow the one day and returning the next. Its first voyage was on the 18th January, 1812.

An old gentleman, eighty-six years of age, and who has been connected with the Clyde for upwards of fifty years, informed me some time ago that he made a voyage in the *Comet* in 1812. He left Greenock at 10 a.m. for Glasgow, but, in consequence of a ripple of head wind, it was 2 p.m. before they got to Bowling, 10½ miles above Greenock, where all the passengers were landed and had to walk to Glasgow, owing to the want of water, the tide having ebbed. It was

no uncommon occurrence for the passengers, when the little steamer was getting exhausted, to take to turning the fly-wheel to assist her.

Henry Bell, like too many pioneers, failed to profit by the successful application of steam to navigation, which has, in the short space of 60 years, so benefited the whole human race; and in his declining years he was chiefly supported by an annuity of £50, granted him by the Clyde Trustees. He died at Helensburgh in 1830, aged 63.

By 1818, passenger steamers were numerous on the river, going as far as Rothesay, Largs, and even Campbeltown. The fares were 4s. to Greenock, and 7s. to Rothesay. Then, in consequence of the shallowness of the river, they sailed from Glasgow only about the top of high-water; now they sail at fixed hours, at all states of the tide, and the fares are 1s. to Greenock, and 1s. 6d. to Rothesay.

The voyager in the early days of steam navigation on the Clyde seldom accomplished the passage up or down the river without undergoing the excitement of feeling the steam-boat run upon one or more of the numerous shoals and sand banks with which the bed of the river then abounded, and, on such occasions, it was the usual practice for the captain to employ his passengers in moving rapidly from one end of the vessel to the other to aid in getting the vessel off the shoal.

Fly-boats for passengers, with sails and oars, were used before the introduction of steam-boats, a whole day being often spent on the passage between Glasgow and Greenock; and lighters, drawing not more than 4 feet 6 inches, have been known, owing to neap-tides, and consequent groundings, to take six weeks to complete the passage from Greenock to Glasgow and back. Steam lighters now do the same double voyage in about as many hours.

Before the year 1818, none of the vessels in the foreign trade came farther up the river than Greenock or Port-Glasgow. Their cargoes were there discharged into lighters, which carried them to Glasgow. These lighters were sailed, rowed, and poled up to Renfrew, and were then towed up to the Harbour by either men or horses.

At this time the largest ship belonging to either Glasgow or Greenock did not exceed 400 tons; 250 tons to 300 tons was the common size, and the largest lighter was about 60 tons.

Steam-tugs, for towing the lighters, followed soon after the introduction of passenger steamers, and in recent years steam has been extensively applied to the lighters themselves. Towing sailing vessels on the river by steam-tugs is now nearly universal. All large vessels employ tugs. Small craft are formed into trains, and each train is towed by one tug. The large fleet of transatlantic steamers which trade between Glasgow and America, and all the larger foreign trading steamers, are taken over the navigation by tug-steamers—one at the bow and one at the stern—under the charge of duly licensed pilots.

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## Shipbuilding.

The shipbuilding trade of the Clyde is now the most important in the kingdom, and a large portion of the mercantile navy of the world is constructed on its banks.

In 1868, the total number of vessels built and launched on the Clyde was 232 of 174,978 tons, including 8 war vessels of 5,384 tons.

In 1869, 240 vessels of 194,000 tons, including 3 war vessels of 9,100 tons.

In 1870, 234 vessels of 189,800 tons, including 1 war vessel of 2,640 tons.

In 1871, 231 vessels of 196,200 tons, including 6 war vessels of 3,050 tons.

In 1872, 227 vessels of 232,100 tons; no war vessels.

In 1873, 194 vessels of 261,455 tons; no war vessels.

In 1874, 225 vessels of 266,200 tons, including 4 war vessels of 2,990 tons.

In 1875, 276 vessels of 228,200 tons, including 3 war vessels of 2,160 tons.

In 1876, 266 vessels of 204,770 tons, including 4 war vessels of 11,370 tons.

In 1877, 228 vessels of 168,000 tons, including 2 war vessels of 800 tons.

In 1878, 279 vessels of 221,432 tons, including 10 war vessels of 15,548 tons.

In 1879, 191 vessels of 168,460 tons; no war vessels.

In 1880, 241 vessels of 239,015 tons, including 8 war vessels of 14,809 tons.

I am indebted for this information to the *Scotsman* newspaper.

I have now brought my, I fear, too lengthened description of the River Clyde and Harbour of Glasgow to a close, yet much has been of necessity omitted that might have given interest. If it has appeared to any too long and tedious, I plead the magnitude of the subjects, the variety of the material, and the difficulty of condensation, and will conclude by quoting the views and opinions of the eminent French Engineer, M. Simonin, expressed by him in an article on "Glasgow and the Clyde," which appeared in the *Nouvelle Revue* of November last:—

"Nowhere as at Glasgow is there revealed in such luminous traits all that can be done by the efforts of man, combined with patience, energy, courage, and perseverance, to assist nature, and, if necessary, to correct her. To widen and deepen a river previously rebellious against carrying boats, to turn it into a great maritime canal, to bring the waters where it was necessary to bring the largest ships, and, finally, to gather a population of 750,000 inhabitants, all devoted to commerce and industry, upon a spot where only yesterday there was but a modest little town, almost destitute of every species of traffic—such is the miracle which in less than a century men have performed at Glasgow."

# ON STEEL.

By JAMES RILEY, Steel Company of Scotland, Limited.

*ON FRIDAY, 18th FEBRUARY, 1881.*

I HAVE been asked by the committee of the Naval and Marine Engineering Exhibition to deliver a lecture on steel. I do not think any justification is necessary for bringing this subject before you, but were such the case, I think it would be found in the increasing magnitude of the number and extent of the works engaged in the manufacture of steel in this district, and in the large and increasing measure of the use of that material in our midst, more especially in connection with shipbuilding and engineering. With that spirit of enterprise and enlightened progress, which is the characteristic of those engaged in these pursuits on the Clyde, the metal "mild steel"—which has been called the metal of the future—had not been long under the notice of the public ere they commenced its use, and the result of their extended experience of its many good qualities has been so satisfactory that, being able to recommend it to their clients, the demand for this class of steel has increased constantly and rapidly—indeed, at a rate which has heavily taxed the powers of those engaged in its manufacture.

I shall have occasion later to return to this, and at present would simply say that, only about three years ago, the Steel Company of Scotland—at that time the only firm in Scotland engaged largely in the manufacture of steel—found that less than 100 tons of "mild steel" produced weekly enabled them to meet all demands upon them for that quality, whereas at present they have difficulty in executing all calls upon them when producing not less than 1,400 tons

weekly; and their efforts have been supplemented by those of one or two other firms in Scotland, who have been induced to commence this manufacture by the largeness of the present and prospective demand. It does, indeed, seem probable that in a very short time Lanarkshire will be the foremost of the "mild steel"-making districts in Great Britain, if not of the world; for, I take it, that the works now complete and in progress will shortly have a producing power of not far short of 4,000 tons weekly of "mild steel" alone. In their total producing capacity they will probably have a yield of nearly 6,000 tons of ingots, requiring about 4,500 to 5,000 tons of hematite pig-iron weekly in its production. Up till recently the pig-iron used in this manufacture was brought from England; now, however, many of the makers of pig-iron in this district have turned their attention to making hematite iron, and I expect that the whole of our requirements will shortly be made at home, and thus the superabundant make of ordinary Scotch pig-iron will be largely reduced.

I doubt not that many of the outside public have been surprised and perplexed at the idea of steel being used in the construction of ships and boilers, the name "steel" being associated in their minds with sharp cutting instruments of hard and, possibly, brittle character. In the same way, but, of course, not to the same extent, many who have been engaged in the use of iron for a long period, and thoroughly understand its characteristics, but who have had no practical acquaintance with the newer classes of "steel," have no doubt had many misgivings as to the propriety of its use in these directions, and also of their own ability to deal successfully with it, should they be required to use it in their ordinary occupations.

These ideas have contributed largely to that disinclination to adopt the "new material" with which steel makers have been so long and so successfully contending.

The application of the term "steel" to the newer classes of this metal was, indeed, unfortunate, so far as the makers were concerned, and has contributed not a little to the many difficulties they have experienced in the conduct of their

business. Even in the minds of experts there has been something approaching to a confusion of ideas regarding these metals through the use of this term "steel," and some efforts have been made to get over the difficulty by a division into classes, whereby the milder or softer should be called "ingot iron," or "homogeneous metal," while the harder retained the older designation of steel; but difficulties, which I need not here enumerate, have prevented the general adoption of this proposal. Now, the definition is pretty generally accepted that steel is an alloy of iron which is cast while in a fluid state into a malleable ingot; yet this does not cover some of the steels to which I shall have to refer.

The history of steel is of great and increasing interest, whether we consider the various processes by which it has been, and is, produced, the inventors of these different processes, with the vicissitudes of fortune through which both have passed, or its application to the various requirements of a constantly-advancing civilization. I do not, however, propose to refer in more than an incidental manner to some of these matters, but I trust that the facts I may lay before you will be found of sufficient interest to warrant their introduction.

Steel, as I have said, is an alloy of iron, and this principally with carbon, and the aim of the manufacturer is to obtain the alloy with such proportions of each as shall best fit it for the purpose for which it is intended. In order to accomplish this, he may adopt some one of the following methods:—

Having ore of sufficient purity, he may reduce it, and obtain malleable iron or steel, by one or other of the direct processes, as they are called; thus dispensing with the usual intermediate stages of manufacture, by which the ore is first reduced in the blast furnace and pig iron produced, to be afterwards, by puddling, &c., made into bar or wrought iron; or, taking the wrought iron so produced, and which may contain too little carbon for his purpose, he may seek by various means to increase its proportion to the iron; or, on the other hand, having crude—or pig—iron, which contains a varying amount of carbon, but in all cases too much to

admit of its being wrought—that is, hammered, rolled, or welded—he may seek to reduce the proportion of carbon present either by removing some of it by oxidation, or by diluting it by increasing the proportion of the iron.

All the various processes for producing steel, whether of ancient or modern times, are based on one or other of these principles, or a combination of them. It is my purpose to-night to describe these various processes, and I trust that, by the aid of the diagrams I have had prepared, I may be able to do so in an intelligible manner.

The most primitive method of making steel of which we have any knowledge is that practised by the natives of India and some other countries, where the ore is reduced in bloomeries, as they are sometimes termed, and of which the Catalan process may be taken as an illustration. The Catalan forge is shown in diagram No. 1. Only the richest and purest ores are used. These are heated in contact with carbon—*i.e.*, charcoal—until reduction takes place, when it is only necessary to remove the spongy mass, and, by hammering, to bring about the aggregation of the particles. The iron thus obtained is broken into small pieces and selected. In making the celebrated Wootz steel, the natives of India pack small pieces of this malleable iron with wood in crucibles, which are then heaped over with some green leaves and clay. About two dozen of these crucibles are packed in one furnace; they are covered over with fuel, and blast is applied for about two and a half hours, when the operation is terminated. The crucibles are broken when cold, and the small cakes of steel removed.

The fact that the production of wrought iron or steel direct from the ore has excited so much interest in the minds of metallurgists is not to be wondered at, when the cost of reduction by means of the blast furnace and of the subsequent necessary operations are borne in mind; hence there have been many proposals for accomplishing this desirable end, but as few of them have passed the experimental stage, and as none have yet been commercially successful on a large scale, I do not think it necessary to take up your time with

a description of any of them. I would simply indicate that the process of Chenot, of Blair, and of Siemens, appear to have come nearest achieving the object aimed at.

In dealing with wrought iron by what is known as the "cementation process," bars are rolled or hammered to the required section; they are then cut to the proper length, and charged into furnaces known as converting furnaces, shown in diagram No. 2. The pots or troughs on the beds of these furnaces, which are made of refractory materials, are strewed with charcoal powder to the thickness of one or two inches, a layer of bars is placed on this bed, and covered with charcoal, on which are again laid alternate layers of bars and charcoal until the troughs are nearly filled, when they are covered several inches thick with charcoal, and afterwards with what is called "wheelswarf," produced at the grinding stones. All the apertures of the furnace are then closed, and the fires lighted on the grates. In a few days the furnace attains its full heat, at which it is kept several days, according to the degree of hardness required, depending upon the amount of carbon in combination with the iron. The progress made in carbonization is tested from time to time after the sixth day by drawing bars from the troughs. When these prove satisfactory the fire is heaped up with small coal, and then allowed to die out. The furnaces are of different capacities, varying from 15 to 30 tons; and this cementation process, as it is called, may be said to occupy about three weeks. The bar steel produced is known as "blistered steel," because when discharged from the furnace the bars are found partially covered by small raised portions of the metal resembling blisters.

On breaking the bar across, the texture is seen to be no longer fibrous, but granular or crystalline; the colour is white, and the crystals are large in proportion to the amount of carbon absorbed.

"Shear steel" is the product from these bars of blistered steel broken into lengths, bundled, or made into faggots, which are rolled or hammered out at welding heat to the form required. This operation is repeated until a sufficiently

uniform texture is obtained, all the loose parts and seams of the blistered steel are closed, and it is now capable of being highly polished; it is also more malleable, and can be forged into shears, edge tools, and cutting instruments. The value of the steel increases with the amount of hammering which it receives; and the terms "double shear," "single shear," &c., express the amount of doubling and welding which the bars have undergone.

Again, steel is made from wrought iron by fusion with carbonaceous matter, as in the case of the Indian Wootz process previously described, and by a process introduced by Mushet, which consists in melting malleable scrap iron with charcoal and oxide of iron in crucibles.

Crucible steel is made in two classes of furnaces, with which it may be as well that you should become acquainted at this point. The first and oldest form is that known as the coke, or melting-hole furnace, shown in diagram No. 3.

The furnace, or melting hole, is a small square or oblong chamber, about three feet deep, and from one and a half to two feet square, lined with refractory material, such as fire-brick, or the silicious stone known as gannister. The top of the furnace is placed level with the floor of the casting-house, the grate bars and ashpit being accessible from below through a vaulted cellar or cave. The cover of the furnace is a square of fire brick, set in an iron frame, with a projecting handle. There is a short flue near the top of the furnace communicating with the stack, which is about 40 feet high, in order to command a strong draught. Several furnaces are usually arranged in longitudinal series on opposite sides of the casting-house, leaving the centre of the floor clear for placing the moulds. Usually two pots or crucibles are placed in a furnace. They stand upon cylindrical discs of fire bricks resting on the grate bars. Previously to being used they require to be gradually heated to redness in an open fire or annealing grate, which is done by placing them in batches of twenty, bottom upwards, together with their covers, upon a bed of red hot coal in the grate; the intermediate space is then filled with coke, and the fire is urged until the necessary heat

has been obtained. The pots are then removed to the melting furnaces, and fixed in position on the stand. The fires are replenished with coke, and as soon as they have been brought up to a strong heat, which takes place in about twenty minutes, the charge, properly assorted and broken into small pieces, is introduced through a wrought-iron funnel, after which the cover is placed on the pot, and the full heat of the furnace is given for three and a half hours, during which time fresh fuel is added every three-quarters of an hour. When the fusion is complete—which is ascertained by removing the cover, and searching the contents of the crucible with a pointed rod—the crucible is cleared from adherent slaggy masses by stirring below the grate, and is then lifted out by the furnacemen with a suitable pair of tongs. The ingot mould made of cast-iron is blackened or coated by various means; and the contents of the crucible, after being allowed to cool for a short time, are then poured into the mould, and its mouth is covered with a plug of cast-iron or a shovelful of sand, in order to prevent the top of the ingot becoming spongy by the escape of gases before solidification.

The crucible, being cleaned, is then returned to the furnace for a second melting. The charge is somewhat reduced, because it is found that the crucibles are reduced in strength at the line of the surface of the previous charge, where a cutting action has taken place by the slag from the fluxes employed; consequently, the consumption of coke and the time of fusion are both reduced in proportion. The furnace is allowed to cool after from three to five meltings have been made, as there is no advantage to be gained by keeping it constantly heated, owing to the corrosion of the lining bricks, produced by the very high temperature, whereby the capacity and power of consuming fuel is increased without a corresponding increase in the amount of steel melted.

I have thought it best in this connection to give you a description of the Siemens' crucible furnace, which depends for its great advantages over the common furnace on the application of the regenerative system and the use of gaseous fuel, although I have not yet brought either of these under

your notice. This furnace is shown in diagram No. 4, and is thus described by its inventor:—

"In the application of the regenerative system to the fusion of steel in closed pots or crucibles, the melting chamber, containing generally twenty-four pots, is constructed in the form of a long trench, 3 feet 6 inches wide at the bottom, and gathered in to under 2 feet at the top. The sides of the melting chamber are arched, both horizontally and vertically, to keep them from sinking together in working, and the work is strengthed by cross-walls at intervals. The pots are set in a double row along the centre of the melting chamber, and the flame passes from side to side, the gas and air from the regenerators being introduced alternately from one side and from the other opposite to each pair of pots. The melting chamber is closed above by loose fire-brick covers, which are drawn partly off in succession by means of a lever suspended from a pulley above the furnace when the pots are to be charged or drawn out. The pots stand in a bed of finely-ground coke dust resting on iron plates.

"The coke dust burns away only very slowly if it is made of hard coke and finely ground; and it presents the great advantage of remaining always in the form of a loose, dry powder, in which the pots stand firmly, while every other material that I have tried either softens in the intense heat, or sets, after a time, into a hard, uneven mass, in which the pots do not stand well. The process of melting carried out in this form of gas furnace is the same in all respects as that in the small air furnaces, or melting holes fired with coke, which are commonly employed; but a great saving is effected in the cost of fuel, and in the number of crucibles required.

"The ordinary consumption of hard coke is between 3 and 4 tons per ton of steel fused; while in the gas furnaces the same work may be done by the expenditure of 15 to 20 cwt. of common coal slack, the cost being, say five shillings against seventy-five shillings per ton of melted steel."

The crucibles used in both the furnaces described are made of mixtures of different kinds of fire-clay, with a certain proportion of ground potsherds and coke dust. The usual

size is from 16 to 18 inches in height, and from 5 to 7 inches diameter at the mouth, with a slight belly at about two-thirds of the height from the bottom; the capacity varies from 35 to 80 lbs. Plumbago pots are now sometimes used, and found to be of advantage in different ways.

When any large masses of cast-steel are required, the contents of all the crucibles are either poured into a foundry ladle before filling the mould, or the pouring is so arranged that, by bringing up relays of fresh pots, a constant stream may be kept up without intermission. Such an operation is one of great interest, and requires careful preparation, and organisation so perfect, that hundreds of crucibles must be ready to be taken out of the furnaces in quick succession, and their contents poured into the common receptacles.

The finest qualities of crucible cast-steel are made by melting cement steel, made from the finest materials, such as the best brands of Swedish iron.

The celebrated Huntzman steel is thus prepared; and it must be understood that the quality of the resulting steel depends, in the largest measure, upon the most careful assorting of the materials charged, which is done by workmen skilled in judging of the blistered steel, &c., to be used.

We come now to consider the different methods adopted for producing steel from crude or pig-iron.

What are known as finery furnaces have been largely used on the continent, for the production of what is known as "natural steel." They are all pretty much of the same type, but vary somewhat in form and dimensions. If you will kindly bear in mind the form of the Catalan forge during the following description of the process, it may help you to a clearer realisation of the operations:—

There is a tuyere blowing into the metal on an open fire; only the blast is more powerful than in the more primitive furnace.

Bauerman thus describes the process as conducted in Styria:—"The first portion of the charge, weighing 120 lbs. is melted down with a small quantity of cinder, the latter being strewed over the coals, the re-heating of the blooms

from the former operation, about 10 or 12 in all, going on at the same time. When only two blooms are left, a further addition of pig-iron is made to the extent of from 30 to 60 lbs., and the blowing is continued until the hearth is filled to within one or two inches of the tuyere. The fire is then allowed to go down quickly, the slag is tapped through a hole in the front plate into a trough filled with water, and the lump of crude steel remaining on the hearth is allowed to cool, out of contact with the air, by covering it with a shovelful of moistened cinders. In about a quarter to half an hour after stopping the blast, the lump is lifted out of the furnace, and is then divided, under the hammer, into 10 or 12 pieces, which are re-heated during the firing of the next charge. The bars drawn under the hammer are hardened by quenching in cold water, and broken, in order to test their quality. They are sorted, according to hardness, into several classes, distinguished by special names. The best are known as 'chisel' or 'tool steel,' 'noble steel,' and 'crude steel,' below which come a variety of steely irons, used for scythe making, waggon wheel tires, and similar purposes."

This process was formerly practised, to a considerable extent, in Styria, Westphalia, and other parts of Europe, but has been rapidly superseded by more improved processes.

What is known as "puddled steel," made in furnaces differing very slightly from ordinary iron puddling furnaces, was at one time largely produced; but this process also has, like the last-named, been superseded, so that I need not trouble you with a description of it. I believe, however, that it may still be seen in operation at the Birkenhead Forge.

I have now to deal with the two processes which have in recent years created—and in fact are still working out—such a great revolution in the iron and steel manufactures of the world.

Before the invention and extensive adoption of the Bessemer and Siemens-Martin processes, steel was a very costly material to purchase, and was produced in compara-

tively small quantities for special purposes, which were restricted within very narrow limits. Now we have works in this kingdom alone equal to a production of something like 1,000,000 tons of Bessemer, and 400,000 tons of Siemens' steel per annum; and the use of the products of these processes is becoming every day more extensive and varied.

The railways of the world are now largely made of these materials, as are also large and increasing portions of the engines, carriages, and waggons which run upon them. The same may be said of the ships of the royal and merchant navies, together with their engines and boilers. Not only in the arts of peace do we find the use of steel largely and rapidly extending, but also in that of war; for not only are rifles made of it from the barrel to the striker needle, but likewise in the construction of guns of heavy calibre, the shell to be fired from them, the carriages on which they are placed, the racers or railways on which they are mounted and trained, and even the armour-plates of vessels at which they may be fired, steel is now rapidly taking the place of iron. If, then, it were interesting to you to know something of the older and more limited methods by which steel has been, and is still produced, much more important is it that you should have that knowledge regarding those more modern and extensive processes by which they are being replaced.

Mr. Bessemer startled the metallurgical world, in the year 1856, by the statement that he had invented a method of manufacturing malleable iron and steel without fuel. In the paper which he read before the Mechanical Section of the British Association at the Cheltenham meeting in that year, he stated that he proposed to accomplish this by treating liquid pig-iron, which had been melted in a cupola or reverberatory furnace, or even been taken direct from the blast furnace, in a special apparatus, by which thin jets of atmospheric air were forced through the liquid metal. No fuel was used or needed in the process, as the temperature was maintained, and even increased, by the combustion of the carbon, and also by the oxidation of part of the iron. Thus, by the oxidation of the carbon, it was so far reduced

that the resulting product was either liquid steel or wrought-iron.

You will, doubtless, be struck by the modest extent of Mr. Bessemer's first patented invention, shown in diagram No. 5. It is simply a modification of the "coke-hole" furnace already described. The crucible is similar, except that provision is made for tapping the metal out into the ingot mould beneath; also, that the cover is altered in form, and perforated, so that the gases generated may escape. Through the centre of the cover a pipe passes down into the fluid metal conducting the air-blast, which is forced through holes at its lower extremity into the fluid metal. From such small beginnings and such simple means have grown the grand and striking operations of to-day conducted in the improved apparatus which Mr. Bessemer afterwards designed, and which gave completeness to his invention.

The converters are usually worked in pairs, one being repaired, or charged, whilst the other is in full use. They are pear-shaped in form, and are of different sizes, some now being capable of taking charges of 15 tons weight, although the most common weight of charge is from 7 to 10 tons. They are suspended on trunnions, and provided with machinery, by which they can be rotated vertically through an angle of 180°. The outer casing is made of wrought iron rivetted together; the lining is made of very refractory materials, gannister being mostly used for this purpose; the tuyeres are perforated by parallel holes about $\frac{3}{8}$-inch diameter, and from seven to twelve in number, and through them the blast is forced into the metal, after having passed through one of the trunnions, which is made hollow, into the wind-box under the tuyeres. The blast has a pressure of from 20 to 25 lbs. on the square inch. The ladle carriage is arranged so that it can be raised and lowered, as well as made to revolve on its axis like a railway turn-table; thus it can be lowered to receive the charge from the converter, then passed out from under the vessel, and afterwards over each ingot mould in succession.

The machinery for moving the converters and the ladle carriage is worked by hydraulic power, and is controlled by

one man placed at a little distance, where he can clearly discern and govern the whole of the operations, including the admission of blast to the vessels. I hope I have given you an idea of the machinery of the Bessemer pit, and will now proceed to describe the manner in which the process may practically be carried into operation; and I do this in the words used by Mr. Bessemer in a paper read before the Institution of Civil Engineers in 1865:—

"The vessel having been heated, is brought into a horizontal position, so that it may receive its charge of melted metal, without the tuyeres being below the surface. No action can therefore take place until the vessel is made to assume the vertical position. The process is thus in an instant brought into full activity, and small, though powerful jets of air spring upward through the fluid mass. The air expanding in volume divides itself into globules, or bursts violently upwards, carrying with it some hundredweights of fluid metal, which again fall into the boiling mass below. Every part of the apparatus trembles under the violent agitation thus produced, a roaring flame rushes from the mouth of the vessel, and as the process advances, it changes its violet colour to orange, and finally to a voluminous pure white flame. The sparks, which at first were large, like ordinary foundry iron, change to small hissing points, and these gradually give way to soft floating specks of bluish light, as the state of malleable iron is approached." "Thus, by the mere action of the blast, a temperature is obtained in the largest masses of metal in ten or twelve minutes, that whole days of exposure in the most powerful furnaces would fail to produce.

"The changes in the colour and volume of the flame, and the kind of sparks thrown off, afford easy methods of judging of the state of the metal. The sound which the metal produces in the suspended vessel affords also a good indication to the workman. Indeed, few processes appeal so strongly to the external senses. When the desired quantity of air has passed through the metal, the vessel is turned on its axis, and the fluid steel is poured out. It is then received in the

casting ladle, which is attached to the arm of an hydraulic crane, so as to be brought readily over the moulds. The ladle is provided with a fire-clay plug at the bottom, the raising of which, by a suitable lever, allows the fluid steel to descend in a clear vertical stream into the moulds. As soon as the first mould is filled, the plug valve is depressed, and the metal is prevented from flowing until the casting-ladle is moved over the next mould, when, by raising the plug, the second mould is filled in like manner, and so on until all the moulds are filled. After the discharge of the vessel the process should be repeated without delay, since the temperature of the vessel is greater after the first charge than it was before, and, consequently, it is in a better condition for the process. Thus, by the control of one responsible man, charges of several tons of crude cast-iron may be converted into malleable-iron, or into steel, in a few minutes, and be cast into ingots of any desired form and weight, suitable for large shafts, or for rolling into rails, merchant bars, or plates."

Such is the Bessemer process, and it can scarcely be wondered at, that when the inventor first made it public, his proposition was (to use his own words), "almost generally looked upon as a chimera, or as the mere day-dream of an enthusiast, which the quiet, every-day practical man felt bound to disbelieve," although the laws on which the whole theory of his invention was based were well known; and hence the process was recognised from the very first by many of the scientific men of the day.

The history of Mr. Bessemer's early difficulties, and how they were gradually, one by one, overcome; of how he determined, in spite of the opinions loudly expressed against the process, to pursue an undeviating course, and to remain silent for years, under the scepticism of those who predicted its failure, rather than again to bring forward his invention until he had himself practically and commercially worked the process—I say this history is one of deep interest, and calculated to excite within us great sympathy for him in his earlier efforts and failures, as well as admiration of the patience and perseverance he exercised under them, and

the powers of mind and fertility of resource manifested throughout.

There had been long an idea that steel might be made on the open hearth of a furnace before Dr. Siemens furnished the means of its accomplishment by the application of the regenerative gas furnace to this end. Of all the plans with this object, that proposed and patented by Heath in 1845 was the first. He conceived that cast steel might be produced by fusing wrought iron and cast iron together on the open hearth of a reverberatory furnace. The wrought iron was to be placed in a separate part of the furnace between the fluid metal and the chimney, and having been there heated by the waste heat of the flame, was to be pushed forward into the bath in order to be dissolved. Heath proposed to heat his furnace by jets of gas, fearing the effect of the ashes from a common fire-place. This process gave great promise of success, but failed from want of ability to obtain the necessary intensity of heat, and to control sufficiently the action and character of the flame.

I pass by other proposed modes of working to mention that known as the Siemens-Martin process.

It is now about twenty years since Dr. Siemens—having, in conjunction with his brother, patented the regenerative gas furnace—first directed his attention to the melting of steel in pots and on the open hearth. His improvements on the ordinary crucible furnace I have already described, but when doing so I passed over the means devised for obtaining the gaseous fuel, a most essential and important part of all his inventions. This is known as the Siemens gas producer, illustrated in diagram No. 6, and which has been described as follows:—

"A brick chamber, perhaps 6 feet by 12 feet, and about 10 feet high, has one of its end walls converted into a grate—*i.e.*, about half way down it is a solid plate, and for the rest of the distance consists of strong horizontal plate bars, where air enters; the whole being at an inclination such as that which the side of a heap of coals would naturally take. Coals are poured through openings above upon this combina-

tion of wall and grate, and being fired at the under surface, they burn at the place where the air enters, but as the layer of coal is from two to three feet thick, various operations go on in those parts of the fuel which cannot burn for want of air. Thus the upper and cooler part of the coal produces a large body of hydrocarbons.

"The cinders or coke which are not volatilized approach in descending towards the grate. That part which is nearest the grate burns with the entering air into carbonic acid, and the heat evolved ignites the mass above it; the carbonic acid, passing slowly through the ignited carbon, becomes converted into carbonic oxide, and mingles in the upper part of the chamber (or gas-producer) with the hydrocarbons. The water, which is purposely introduced at the bottom of the arrangement, is first vapourized by the heat, and then decomposed by the ignited fuel, and rearranged as hydrogen and carbonic oxide, and only the ashes of the coal are removed as solid matter from the chamber at the bottom of the fire-bars."

In the lecture which Dr. Siemens recently delivered here, he described an improved form of gas-producer which seems to give promise of many useful improvements on the one now in general use, and which I have just referred to.

On diagram No. 7 you have an illustration of the Siemens open-hearth regenerative furnace, which Professor Faraday thus lucidly describes:—

"The gas from the producers rises up a large vertical tube for 12 or 15 feet; after which it proceeds horizontally for any required distance, and then descends to the heat regenerator, through which it passes before it enters the furnace. A regenerator is a chamber packed with fire-bricks, separated so as to allow of the free passage of air or gas between. There are four placed under a furnace. The gas ascends through one of these chambers, whilst air ascends through the neighbouring chamber, and both are conducted through passage outlets at one end of the furnace, where, mingling, they burn, producing the heat due to their chemical action.

"Passing onward to the other end of the furnace, they—*i.e.*,

the combined gases—find precisely similar outlets, down which they pass; and traversing the two remaining generators from above downwards, heat them intensely, especially in the upper part, and so travel on in their cooled state to the shaft or chimney. Now the passages between the four regenerators and the gas and air are supplied with valves and deflecting plates, which are like four-way cocks in their action, so that by the use of a lever those regenerators and air-ways, which were carrying off the expended fuel, can in a moment be used for conducting air and gas into the furnace; and those which just before had served to carry air and gas into the furnace, now take the burnt fuel away to the stack.

"It is to be observed that the intensely-heated flame which leaves the furnace for the stack always proceeds downwards through the regenerators, so that the upper part of them is most intensely heated, keeping back, as it does, the intense heat; and so effectual are they in this action, that the gases which enter the stack to be cast into the air are not usually above 300° Fah. of heat. On the other hand, the entering gas and air always pass upwards through the regenerators, so that they attain a temperature equal to a white heat before they meet in the furnace, and then add to the carried heat that due to their mutual chemical action. It is considered that, when the furnace is in full order, the heat carried forward to be evolved by the chemical action is about 4000° Fah., whilst that carried back by the regenerator is about 3000° Fah., making an intensity of power which, unless moderated on purpose, would fuse furnace and all exposed to its action. Thus the regenerators are alternately heated and cooled by the outgoing and entering gas and air, and the time for alteration is from half an hour to an hour, as observation may indicate. The motive power on the gas is of two kinds: a slight excess of pressure within is kept up from the gas-producer to the bottom of the regenerator, to prevent air entering and mingling with the fuel before it is burned; but from the furnace downwards through the regenerators the advance of the heated medium is governed mainly by the draught in the tall stack or chimney."

As in the case of Sir Henry Bessemer, so again in that of Dr. Siemens, the difficulties and disappointments which attended his efforts to introduce his process, and secure its adoption by manufacturers were such as would have daunted and overcome a less resolute spirit; but here again there is the same confidence that success is possible, combined with the determination that it shall be achieved, and the necessary powers of mind and of resource to justify both the confidence and determination.

The result of his labours is manifest in the high estimation in which his process is now generally held, especially where finer qualities of steel are required for purposes where uniformity and regularity in the product are of vital importance.

Dr. Siemens states that, "having been so often disappointed by the indifference of manufacturers and the antagonism of their workmen, I determined in 1865 to erect experimental or 'sample steel works' of my own at Birmingham for the purpose of maturing the details of these processes before inviting manufacturers to adopt them. The first furnace erected at these works is one for melting the higher qualities of steel in closed pots, and contains sixteen pots of the usual capacity. The second, erected in 1867, is an open-hearth furnace, capable of melting a charge of 24 cwt. of steel every six hours. Although these works have been carried on under every disadvantage—inasmuch as I had to educate a set of men capable of managing steel furnaces—the result has been most beneficial in affording me an opportunity of working out the details of processes for producing cast steel from scrap-iron of ordinary quality, and also directly from the ore, and in proving these results to others."

I have already given you a description of the furnace as used for steel-making; but this is not sufficient for a full understanding of the *modus operandi* of the process. Let us suppose that we are commencing operations with a new furnace. This having been dried by means of a wood fire kept alight on the bottom or hearth, the gas valve closing the connection with the tubes of the gas-producer previously described is opened to a slight extent, as also is the valve for

closing the tube by which air is admitted; the reversing valves are fixed to direct the air and gas to one pair of regenerator chambers under the furnace; these are gradually passed through, and the air and gas are conducted through several flues until they meet at a given point in the furnace, when combustion takes place, and the flame, passing slowly through, escapes by corresponding flues at the opposite end, and through the other pair of chambers to the chimney flue. I have already stated how the heat, which would otherwise become waste, is caught and stored up in the regenerator, and how, upon the direction of the currents of gas and air being reversed, this heat is taken up by them, and elevates their temperature to a very high degree, so that upon combustion taking place in the furnace, a heat of great intensity is obtained, and that at the exact point where it is most required and is of most advantage. Under this treatment the furnace is gradually made hotter, and the furnaceman commences to make the bottom. This is done by spreading thin layers of a selected sand over the brick-work of the bottom; each layer is fused before another is laid on, so that, at last, the surface assumes the form of a shallow basin, solid and impervious, and requiring only very slight repair after the working of each charge. The furnace being thus prepared, the pig-iron and heavier portions of the scrap are charged into the furnace through the doors provided for the purpose. The furnaceman is careful to distribute his charge so as to obtain the greatest effect from the flame, that it may be quickly melted, placing the scrap on the banks of the furnace where it may be thoroughly heated prior to being turned down to be dissolved in the bath of melted pig-iron. After a time the whole of the pig is melted, the scrap is turned down, and smaller scrap is thrown in at intervals. During these operations the bath has become covered with a coating of slag, which tends to protect it from the action of the flame. This slag the furnaceman endeavours to "clean," as he terms it—that is, to free it from iron, by the addition of limestone or other fluxes. By-and-by the furnaceman inserts a long-handled spoon and takes out a sample of the metal, which he

cools in water, and afterwards hammers and breaks. By the behaviour of this sample—its hardness or malleability, and by the appearance of the fracture—he judges of the stage at which the charge has arrived. After frequent samples taken he is satisfied as to the point of decarbonization reached, then samples are submitted to the chemist, who finally passes the charge as being what is required. Thereupon a quantity of spiegeleisen or of ferro-manganese is, after being heated to redness, charged into the bath, and the whole is tapped out into the ladle. This is done by the insertion of a strong pointed bar into the tap-hole, which has been very carefully formed in the process of making the bottom, and closed with a special mixture before throwing in the charge. The ladle is suspended on a carriage, and various means are adopted for bringing it over each of the ingot moulds in turn, when, as in the Bessemer process, the steel is tapped out of the bottom of the ladle. The charges worked in the earliest furnaces weighed, as we have seen, about 25 cwt. each; now 10, 12, and even 16 tons are dealt with in one operation.

This is the Siemens-Martin process; but the Siemens process differs from it in some particulars. Very little scrap, sometimes none at all, is used; but the charge consists mainly, or entirely, of pig-iron, which is placed on the bottom and round the sides of the furnace in the manner previously described. Melting requires four or five hours; then ore of pure character is charged cold into the bath, at first in quantities of four to five cwt. at a time. Immediately this is done, a violent ebullition takes place; and when this has abated, a new supply of ore is thrown in—the object being to keep up uniform ebullition as nearly as may be. Of course care is taken that the temperature of the furnace is maintained, so as to keep the bath of metal and slag sufficiently fluid; but after the lapse of some time, when the ore is thoroughly heated and reduction is taking place rapidly, the gas may be in part shut off the furnace, the combustion of the carbon in the bath itself keeping up the temperature. In the course of the operation, the quantity of ore charged is gradually reduced, and samples are taken from time to time of both slag and

metal. When these are satisfactory, spiegeleisen or ferro-manganese are added, and the charge cast, as in the previous case.

This mode of working takes rather more time than the scrap process, and the consumption of fuel is rather larger; but it has this advantage, that there is greater certainty as to the result, because of the known composition of the materials charged, which cannot be the case in dealing with large quantities of scrap, obtained, it may be, from a thousand sources. Then, again, the loss on the pig by the removal of its silicon and carbon is about compensated by the iron obtained from the ore which has been used to furnish the oxygen for decarbonization.

There is another form of open-hearth furnace, known as the Pernot, which has been adopted at one or two works in France, and which is shown in diagram No. 8. The hearth is of circular form, is separated from the body of the furnace, and is supported on a movable carriage.

It is also arranged that it can be rotated on its axis, which is inclined at an angle of 5° or 6° to the vertical. In charging the furnace, the pig-iron, previously heated to redness in an auxiliary furnace, is placed on the bottom with the whole of the scrap over it. The bed or hearth is then made to revolve slowly, and each piece of scrap is alternately exposed to the full heat of the flame, and dipped in the bath of metal which soon begins to form. The fusion is thus very rapid—the whole charge, of about five tons, is fluid in about two hours. Samples are then taken out at intervals, and when the metal is sufficiently soft, spiegel is added, and the charge is tapped out. It will be seen that in this system also the regenerative system is adopted—the form and positions of the chambers, and the ports, or flues, being modified to suit the other portions of the arrangement. When repairs are necessary, either to the bed, or roof, or ports, the carriage is withdrawn, so that these may be done with greater ease, and with less loss of time.

Two of these furnaces have been erected at Blochairn works, and have been under trial for some time, but at present I am

not able to state that there is any balance of advantages in their favour when compared with the modern Siemens' furnaces working alongside them.

If you think for a moment on what I have said, you will no doubt, perceive that up to this point my sole aim has been to make you acquainted with the different processes by which steel is manufactured, and with the machinery and apparatus used in each; also, that I have hitherto almost disregarded both the raw materials used and the quality of the resulting product. I set out with the statement that steel is an alloy of iron and carbon, and up to the present have directed your attention simply to the means of obtaining this alloy with the desired proportions.

As you are aware, good wrought-iron has the properties of malleability and ductility to a large extent, and its tensile strength is considerable. Now the addition, within certain limits, of carbon to iron has the effect of reducing its malleability and ductility; but its tensile strength is increased, and it acquires the property of hardening and tempering when, after being heated, it is suddenly quenched in cold water. I have said that this is the case when carbon is added within certain limits, and it will probably astonish you to know how narrow these limits are. Thus steel attains its greatest tensile strength when only about 1 per cent. of carbon is present, when it has an elastic limit of about 30 tons, with an ultimate tensile strength of about 60 tons on the square inch of sectional area; but this steel has but little ductility, and is comparatively brittle. Hence it is not adapted to the wants of the engineer for constructive purposes, although it may be well suited to other requirements. From this you will perceive that it is necessary for the steel-maker to vary his practice, at one time supplying steel with not more than $\frac{1}{1000}$th per cent. of carbon, having a low tensile strength, but great ductibility, as in the sample before you. Next he is called upon to supply steel for boilers and ships which shall come within strictly specified limits as to strength and ductility, and the carbon will be 0·15 to 0·20 per cent., then he may have to give a steel for structural purposes, with a

higher breaking strain, but necessarily less ductility, and the carbon may be increased to say 0·3 to 0·35; or, again, a *harder* steel may be required, especially prepared to resist wearing action without sacrificing strength, &c., as in rails and tires, and the carbon becomes 0·4 to 0·5 per cent.; but still the catalogue is not exhausted, and the maker is called upon to furnish steel with all shades of temper due to carbon between this point and up to 1·25 per cent.

Now this would be comparatively easy of accomplishment if it always followed that, given the iron and carbon, the tests proposed would be satisfied; but, unfortunately, there may be phosphorus present, when the brittleness of the steel is increased largely, and its ability to withstand a blow greatly impaired—the steel is, consequently, unfit for its purpose, although it has the qualities of working well through the different operations by which it is changed from an ingot to the finished product. Then, again, there may be sulphur present, and what is called "redshortness" results—that is, the steel cannot be forged or rolled at all if it is present in considerable quantities, and only with great care and with imperfect results if only in moderate proportions. If the operations are completed, however, it does not appear that sulphur has any deleterious effect, but possibly may slightly increase the strength of the steel, as it does when present in cast-iron. Again, silicon is sometimes found in the steel, and may have been in excess in the iron used, and the resulting quality will be very unsatisfactory; or sometimes copper, and again redshortness will trouble the workmen.

All these elements have been greatly objectionable to the manufacturer of steel; hence only the purest materials have been used, and the science of the chemist has been called in, to enable the manufacturer to choose rightly and use judiciously all the materials he requires.

Now, Mr. Bessemer has told us that he was unsuccessful in his earlier efforts to produce good steel, because he endeavoured to do this from ordinary pig-iron; that he was successful when he used Swedish or other iron, free from impurities; and from this circumstance has sprung the great

development of the manufacture of hematite pig-iron, the purest made in this country, and the best qualities of which are known as Nos. 1, 2, and 3 Bessemer. These qualities are almost free from sulphur and phosphorus, but contain sometimes as much as five per cent. of silicon, which has been considered by makers of Bessemer steel rather an advantage than otherwise, because in its combustion the heat developed is very great, and useful in the working of the charge. For this reason, as well as because of its purity, grey pig-iron—the greyness being in part due to silicon—is always used in the Bessemer converter, while in the Siemens' process, a closer iron, say Nos. 3 and 4, is used; but it is always a stipulation that the silicon should be as low as possible, and that the sulphur should not exceed 0·06, or phosphorus more than 0·5.

Regarding the latter element, however, the belief has always been held since the make of steel attained such huge dimensions, that methods would be discovered by which it would be eliminated from the iron, and thus the immense deposits of phosphoric iron ores in this and other countries would be rendered available for steel-making. The immense importance to those engaged in iron-making, of such a discovery naturally stimulated chemists and metallurgists to unwearied research and experiment; but it has been reserved to two young men—Messrs. Thomas and Gilchrist—to practically solve the problem. I cannot stop to fully describe their process, but would simply state that it depends for its success on the possibility of substituting a basic for an acid slag in either the Bessemer converter, or the Siemens, or other open-hearth furnace.

Chemists would not experience any difficulty in producing this slag, with which the phosphorus in the molten iron would combine, and leave the iron practically pure; unfortunately, however, both the converter and the furnace were in all cases lined with acid materials, so that in vessels thus lined it was impossible to retain the basic character of the slag, on which everything depended. What Messrs. Thomas and Gilchrist have accomplished is, in addition to the pro-

duction of a basic slag by certain specified means, they have made bricks of basic materials, and of such character that the converters and furnaces may be lined with them, so that the character of the slag shall not be injuriously modified during the remainder of the operations. This discovery, although apparently of so very simple character, is no doubt destined to produce a revolution in the steel manufacture of the world. I am not sure that, in this country, except in very special cases, it will enable those who use it to compete successfully with those using hematite iron, so long as the latter can be produced at a cost so nearly approaching to that of phosphoretic pig-iron; but I have no doubt that on the Continent, where phosphoretic pig can be produced in very large quantities, and at a very low cost, and where hematite iron was either imported from this country, or produced at a high comparative cost, the margin between the costs of the two different kinds of pig-iron will enable those who adopt the new process, not only to work at a considerable profit over their former practice, but also, by reducing the cost of the steel made, constitute them formidable rivals in their own and foreign markets, and make them independent of supplies of hematite pig-iron from this country.

I must now refer to another element which plays an important part in the operations of the steel-maker—that is, the metal "manganese." I have referred to "redshortness" as being due to the presence of sulphur in the steel, but Mr. Bessemer, like all other steel-makers since, was troubled with a redshortness in his ingots due to another cause than the presence of sulphur. This was the presence of either oxygen or carbonic oxide in very appreciable quantities, locked up in small cells, giving the ingot the fault now known as being honeycombed. This defect threatened to be fatal to the process were not a remedy found. Now, some years before this, Heath had discovered the beneficial effect of manganese in the crucible process, and had taught the Sheffield steel-maker to use it either as oxide of manganese, or in some carburetted form. They recompensed him by breaking his heart, through the constant litigation to obtain the reward

due to his invention. More recently, Mushet had patented the use of spiegeleisen, which contained varying quantities of manganese, and he suggested that by using this iron at the close of the blow the manganese, being readily oxidizable, would combine with the oxygen forming the cells, or honeycomb, and so the difficulty would be got over. This was in fact the case, and from that time to this the alloys of iron and manganese have been constantly growing in importance. You will now understand why I said that the making of steel with a certain quantity of carbon could be easily accomplished—for it was only necessary to "blow" the metal to a certain point in the Bessemer process, or to dilute it, or to burn it out by charges of ore in the Siemens-Martin or Siemens process, until the iron was thoroughly decarbonized, then to add a calculated quantity of spiegeleisen (which, with varying quantities of manganese, always contained a nearly uniform quantity of carbon), and the result was attained, if the operation was carefully conducted. But spiegeleisen, in those days, contained only about 9 or 10 per cent. of manganese; and as it was found to be necessary that the steel should contain not less than 0·3 per cent. of manganese, this could not be added without so increasing the carbon that it was impossible to make what we now call soft steel; hence attention was at once given to the manufacture of spiegel as rich in manganese as possible. This was accomplished so far that as much as 30 per cent. of manganese was obtained. But the manufacture has been carried to a higher pitch in the production of ferro-manganese, where the manganese present has been increased to even 80 per cent. Thus the means of increasing the manganese in his steel without adding to the carbon, or of decreasing the carbon without losing his manganese, was placed in the hands of the manufacturer; and it was rendered possible to produce the remarkably fine qualities of soft steel which have been made in recent years, of which specimens are before you.

Thus manganese is of very great use to the steel-maker, and when used in combination with silicon and iron in the form of the alloy now before you, it enables us to produce the

very fine castings which are to be found in this Exhibition. This alloy is the invention of the Terre Noire Co. in France, who have made great use of it in the production of fine castings of large size in the shape of marine engine shafts, &c. Their process is in the hands of the Steel Company, who are applying it to the production of the various parts of engines, stationary, locomotive, and marine, and to many other important requirements of engineers and others.

Manufacturers were not slow to avail themselves of the opportunity thus afforded them, and the result has been the immense development in the production of "mild steel" or "ingot iron," to which I referred in my opening remarks. Naturally the fitness of this class of steel for ships and for boilers was at once recognised. Having greater tenacity than the best Yorkshire iron, with as large an amount of ductility, also having this higher tenacity nearly equally in all directions of the plate, steel at once commended itself to the boiler-maker. The use of steam at higher pressure for marine engines was made increasingly possible. Engineers had already reached the limit it seemed possible to attain while using iron, for plates were now $1\frac{1}{4}$ inch thick in iron. As it was possible to have a boiler of the same strength as iron with the scantlings of steel reduced 25 per cent., it is evident that by retaining the same scantlings in steel, the pressure might be very largely increased without any increase of risk to safety, or of difficulty in construction.

Then, again, it was recognised that if advantage was taken of the superior strength of steel to reduce the thickness of the internal plates of boilers, the increased steam generating power would be very valuable and useful. Further, in practice it has been found that although steel is much higher in price than common iron, it is much lower than Low Moor or best Yorkshire iron, and that when all the facts of the case are fully considered, a boiler may be built of steel at about as low a first cost as one built in the ordinary style of iron. Then, again, the boiler-maker has found that he has less trouble with defective plates when using steel, and this is an important matter to him. It is, then, no wonder that the

use of steel for this purpose has very largely developed; and I have the authority of Mr. Parker, of Lloyd's Registry, for stating that, with the exceptional case of the "Livadia's" boilers, out of all the thousands of tons of steel boilers which have come under their survey, they have not had one single case of failure or of trouble. There have been cases when, in the course of construction, plates have been torn or cracked, but he states that in every case the cause is known, and cannot be charged against the qualities of the steel used.

The British Admiralty led the way in the "new departure" in shipbuilding, so far as this country was concerned, and in connection with the supply of the material for the construction of the "Iris" and "Mercury" for the Admiralty, I had the honour, about six years ago, of reading a paper before the Institute of Naval Architects in London, in which the qualities of the metal were described and its behaviour under various tests indicated.

Mercantile owners, however, were very slow to patronize the "new metal," and I well remember the anxiety I then experienced to obtain a contract for the supply of steel for a merchant vessel. This was at last accomplished in Newcastle. The ice was thus broken, but progress was disappointingly slow. The Admiralty followed up their first venture by contracting for six corvettes to be built of steel by Messrs. Elder & Co. The owner of the merchant vessel to which I have referred had such satisfactory returns from her that he contracted for a second vessel. Meanwhile the use of steel had been engrossing more and more of the consideration of shipowners and builders, and many small ventures were made, until at length the great companies took the matter up. Messrs. Allan led the way with the "Buenos Ayrean," and were quickly followed by the Pacific Steam Navigation Co., Mr. Donald Currie, the Peninsular and Oriental Co., the British India Co., the White Star Co., the Cunard Co., the Orient Co., and many others—the latest and grandest of the vessels built of steel being the "Parisian" and the "Servia," launched the other day into the Clyde.

I have already named the small quantity of steel which

sufficed for the requirements in 1878; it has been stated that in the following year 19,000 tons of steel vessels were launched on the Clyde alone, while last year the tonnage was increased to 43,000 tons.

We claim that vessels built of this mild steel are much safer than those built of iron, that there is less risk of loss with them, and we, therefore, contend that they ought to class higher, and ought to be insured at lower premiums; also that being lighter, because of the reduction of scantling allowed as compared with iron, their earning power—especially when carrying deadweight cargo—is so much increased that they make very handsome returns for the additional first cost due to the use of steel.

In support of my statement that steel vessels are safer, I might quote many cases where they have withstood trials that would probably have seriously injured iron ships in similar circumstances, but I content myself with referring to two striking instances. The photograph before you shows the steel plates cut out of the "G.M.B.," a vessel belonging to Messrs. James Watson & Co., of this city, after she had been in collision at sea. You will see that they are bent and crumpled up in fearful style, yet not one is cracked. It was the opinion of experts who saw her after the collision that, had she been built of iron, she must have inevitably sunk. The other is a more striking instance, and was related by Mr. Wm. Denny, of Dumbarton, to the Institute of Naval Architects:—

"The 'Rotomahana' had a very narrow escape from total loss on 1st January. She was engaged in an excursion from Auckland to Great Barrier Island, a distance of fifty miles, and was leaving the harbour of Fitzroy (in Great Barrier Island) by a somewhat difficult passage, when she struck on a sunken rock with considerable force. She made some water in the way back to Auckland, as it afterwards turned out, through some rivet holes; these were plugged, and she was enabled to return to Dunedin to be docked. The enclosed report from our marine superintendent will explain the nature of the damage. The worst damaged plate was taken

out, re-rolled, and replaced. Several frames were set back, and a good job made of the repairs within seventy-two hours.

"*This experience has shown clearly the immense superiority of steel over iron. There is little doubt that, had the 'Rotomahana' been of iron, such a rent would have been made in her that she would have filled in a few minutes.* A number of frames were set back by the force of the blow, the bulkhead was bulged, and the plate was corrugated, *and yet there did not appear one crack anywhere.*"

## EXTRACT FROM REPORT, &c.

"On examining the bottom it was found that, on the starboard bilge, at the bulkhead, between the forehold and the stock-hole, about 20 feet of the fourth strake from the keel was all more or less indented—one plate particularly, 14 ft. × 37 ins. × $\frac{1}{2}$-in. thick, being very badly indented between the frames. This plate we decided to remove, and started doing so at 7 p.m. on the 7th instant.

"The removal occupied 24 hours, as all our tools broke in the work, and a new set had to be specially made to stand the steel. The plate looked so bad that it was doubtful whether it was worth while spending any time over it; however, we decided to give it a fair trial, and it was put in the furnace and heated for two hours, then taken out and hammered on the blocks.

"This process had to be repeated three times before the rollers would take it in, but when it had passed through the rolls it really looked like a new plate, perfectly sound and good. In working it stretched $\frac{3}{16}$th of an inch, but by paring a little off the ends, the rivet holes, at both the landings, and the butts came in exactly as required for a true fit. Seven of the frames were badly bent, with a sharp curve tending both inwards and aft—two being bulkhead frames, with double angles, and very strong.

"The floors were cut, and the frames thoroughly examined, but we found no sign of crack or strain in the material. The frames were heated and re-straightened, and riveted to the floors. All the riveting was completed by 6 p.m. on the 10th instant.

"It may be here stated that, had the frames been composed of iron, instead of the splendid ductile material of which they are

composed, they would all require to have been renewed, and even then they would not have made such a complete job as the present.

"(Signed) A. CAMERON,
"*Marine Superintendent.*

"*15th January*, 1880."

But what are the alleged disadvantages of the use of steel? First, that its cost as compared with iron is too great. This objection was a formidable one when plates were sold at near twenty pounds a ton, but since then constant and unremitting efforts have enabled steel-makers to reduce the price within such limits as may be called reasonable, and will enable the vessel to earn a good return on the increased expenditure. Doubtless the increased competition due to the rapid extension of steel-works will sharpen our wits, and compel us to adopt, or to find out, means of producing at a lower cost, that so the demand may be sufficiently increased to find occupation for us all.

I am informed that there will be built this year, under Lloyd's Survey alone, something like 700,000 tons of shipping, requiring in its construction from 250,000 to 300,000 tons of iron or steel, and although this may be an exceptional year, yet it will not be for want of great exertions on the part of steel-makers if they do not obtain a due share of orders, which are sufficiently large to employ at least six times the power of production possessed by the Steel Company of Scotland.

Then, it is stated by some inexperienced people that steel is more difficult to work in the ship-yard. Against that I may quote the testimony of those who have used steel most extensively. Messrs. Denny, who have had contracts requiring 18,000 tons of steel, inform me that their men prefer working steel rather than iron, and that if they could obtain contracts for steel vessels sufficient to keep their yard full, they would not build another iron vessel. Further, it is stated that steel vessels, being built with reduced scantlings, want stiffness. Now, this being the result of unsuitable designs—the metal not being properly distributed—it is

evident that the skill of our naval architects will quickly remedy that defect, if it exists in reality, and not in the imaginations of the hypercritical only.

Then a great deal is said about corrosion. But this cry of the liability of steel to excessive corrosion, if not raised, has been greatly magnified by our "friends" who, by the animus evident in what they say and write, appear to indicate that they are not particularly disinterested in their statements. A great deal has been made of the case of the "Iris," which the Admiralty have had examined, but I have it on undoubted authority that the case has been greatly exaggerated, and that the officials at the Admiralty had experienced no uneasiness or alarm in regard to her condition. As positive evidence against the statements as to corrosion, I can refer to many instances in which the anxiety of owners have led to careful examinations of ships and boilers built of steel, without any trace of corrosion or pitting. I feel, therefore, that I am warranted in speaking strongly against the efforts being made to damage the character of steel in this respect.

Now I come to consider what appears to be the most serious charge of all. It is fashionable amongst a certain class to talk of the "mysterious behaviour of steel," to shake the head, shrug the shoulder, look wise and serious, and talk of its "unreliable character," "its utterly untrustworthy qualities," in strains which make the inexperienced feel that the less they have to do with steel the better. Now, for a long time we have accepted all this condemnation as meekly as might be; we have occasionally ventured to express our opinion that unwarrantably hard things were being said of steel, that we hoped all was not true that was said, or at least that the statements were somewhat exaggerated.

We have endeavoured by careful work to prevent accumulation of evidence on the part of accusers, have "bided our time" until the use of steel should be greatly extended, and until the people using it should be greatly increased in number. I think the time has now come when we can assume a different attitude, and, allowing our enthusiastic feeling with regard to steel to have full sway, say to the detractors, "Upon

you lies the *onus* of proof" that steel is unreliable in character and untrustworthy in use as compared with iron. We direct you, in refutation of the statement, to the rigid character of the tests we undergo, while anything that will hold together in the shape of iron may be put into a ship. We ask you to note the extremely few failures which have occurred in steel in the ship-yard, and contrast it with the failures in iron. I remember that, when nearly 7,000 tons of steel had been used in one of our ship-yards, not more than three plates had failed in working, and it was admitted that in two of these no fault could be found with the metal; while in the same yard a small vessel was being built, requiring about 40 tons of iron, and I saw no less than seven plates which had failed in working.

During the time that Lloyd's insisted upon rigidly testing steel in the ship-yards, instead of at makers' works, the total rejection of plates, &c., for not satisfying the required rigorous tests was very small indeed, and those which were so rejected were very much superior in quality to the iron in common use. Why then should we steel-makers submit to this stigma being attached to our production? We know that although there may be some few exceptional failures, yet they form an infinitesmal portion of the very large whole of our make; the metal which we send out of our works is worthy of the utmost confidence, and justifies the pride with with which we refer to its many good qualities.

I have long felt very strongly on this point, and although it has not, I am happy to say, fallen to the lot of my Company to have many complaints as to the quality of their productions, but rather the reverse, I have felt that scant justice has been done to makers of "mild steel," who have spared no expense or care in their efforts to achieve the success at which they have aimed, and who have sought for and made use of all the knowledge, scientific and practical, which was within their reach.

CATALOGUE WITH SUPPLEMENT.]

# Naval and Marine Engineering Exhibition

Corporation Galleries, Glasgow
1st November 1880 till 30th April 1881

Introductory Sketch of the Rise and Progress of Steam Navigation, more especially on the River Clyde, by W. J. Millar, C.E., Secretary to the Institution of Engineers and Shipbuilders of Scotland.

Glasgow: Printed by Robert Anderson, 22 Ann Street
1880.

WHEREAS, by the "Protection of Inventions Act," 1870, it is stated to be expedient that certain protection specified in the said Act should be afforded to persons desirous of Exhibiting New Inventions at International Exhibitions to be held in the United Kingdom. And whereas the Committee of the Naval and Marine Engineering Exhibition, Glasgow, have represented to the Board of Trade that they are desirous of holding an International Exhibition of Models and Apparatus connected with Naval Architecture, Marine Engineering, and Navigation, in the Corporation Galleries, Glasgow, from the first day of November, 1880, to the thirtieth day of April, 1881, both days inclusive, and have made application to the Board of Trade that such protection as is afforded by the said Act may be extended to Inventions exhibited at the said Exhibition.

Now, therefore, the Board of Trade, by virtue and in exercise of the powers conferred upon them by the "Protection of Inventions Act," 1870, do hereby certify that the aforesaid Exhibition of Models and Apparatus connected with Naval Architecture, Marine Engineering, and Navigation, proposed to be held in the Corporation Galleries, Glasgow, from the first day of November, 1880, to the thirtieth day of April, 1881, both days inclusive, is, in their judgment, calculated to promote British Industry, and to prove beneficial to the industrious classes of Her Majesty's subjects.

Signed by order of the Board of Trade, the twenty-first day of August, 1880.

HENRY G. CALCRAFT,
*Assistant Secretary, Board of Trade.*

# SKETCH

OF THE

# RISE AND PROGRESS OF STEAM NAVIGATION,

## MORE ESPECIALLY ON THE RIVER CLYDE.

BY W. J. MILLAR, C.E.,

*Secretary to the Institution of Engineers and Shipbuilders in Scotland.*

**(1) Historical.**—Amongst the earliest records of attempts to utilize steam for the propulsion of boats is the patent of Jonathan Hulls, in 1736, for a tow-boat having a rotary paddle at its stern, driven by a steam apparatus placed in the body of the boat.

Denis Papin, born in 1647, appears to have invented a steamboat in 1707, in which he ascended the Weser. The boat, however, was destroyed by the people as an innovation of a doubtful character.

In 1788 Patrick Miller, in connection with Symington & Taylor, tried a small steamboat on Dalswinton Loch. This vessel was double, and measured 25 feet in length by 7 feet in breadth, and had two wheels—one before and the other behind the engine. The speed obtained appears to have been five miles per hour.

In 1789 the same inventors tried a larger vessel on the Forth and Clyde Canal, near Carron, and a speed of about seven miles per hour was obtained.

In 1802 the "Charlotte Dundas" was tried on the Forth and Clyde Canal. She had one paddle wheel at the stern, with a direct-acting horizontal engine.

In 1807 Robert Fulton fitted out the "Clermont." This steamer plied on the Hudson River, and was 130 ft. in length by 16½ ft. in breadth. The engine was 18 horse-power, having a cylinder 24 in. diameter, with a 4-ft. stroke, and was made by Boulton & Watt.

In 1809 the steamer "Accommodation" was started on the St. Lawrence river.

In 1812 Henry Bell started the "Comet." She was 42 ft. long by 11 feet broad, draft 5 ft. 6 in., and had at first two paddles at each side, and was built by John Wood, at Port-Glasgow. The engine was somewhat of the side lever type, and was of

about 3 horse-power, and made by John Robertson, at Glasgow. The vessel was afterwards lengthened to 60 ft., and fitted with a new engine and a single pair of paddles, and attained a speed of five or six miles per hour. The "Comet" at first plied to Greenock and Helensburgh, and about 1815 appears to have plied on the Forth between Newhaven and end of Forth and Clyde Canal. Afterwards, while on the Fort-William route, she was lost in 1820 at Craignish.

The next steamer, built in 1813, was the "Elizabeth." She was a larger vessel than the "Comet." Her engines, of 10 horse-power, were made by James Cook, of Tradeston. This steamer was followed, in the same year, by the "Clyde," built by John Wood and engined by J. Robertson. She was 72 ft. keel and 14 ft. beam. The engines, of 14 horse-power, had a 22-inch cylinder, with a 2 ft. stroke. These steamers were followed in after years by still larger vessels, amongst which were the "Glasgow" and the "Marjory." The latter went to the Thames in 1815, and was the first steamboat plying on that river. The length of this boat was 60 ft., with a breadth of 12 ft. The engine was 10 horse-power, with a cylinder of 20 in. diameter and 2 ft. stroke.

During the first ten years succeeding 1812 forty-eight steamers were built on the Clyde. These were all of wood, the deck being spread out on each side of the hull, and the paddle-boxes well forward, leaving a short forecastle and long after-end. As a type of these early Clyde steamers, we have still amongst us the "Industry," now lying in Bowling Harbour. This steamer was built in 1814, and engined by Mr. Thomson, of Tradeston, who had early turned his attention to the propelling of boats by paddle wheels. This vessel is well worthy of study, as showing the style of building then adopted, and the form of engine fitted on board of the boats during that period and for several years after. One peculiarity was in the use of spur wheels to connect the engine shaft with the paddles. The "Industry," and a similar boat, the "Trusty," were goods-carrying steamers between Glasgow and Greenock, the former running till about ten years ago.

The first tugboat on the Clyde was the "Samson," about 1820, and engined by Duncan M'Arthur.

The last wooden passenger steamer to ply on the Clyde was the "Dunoon Castle," 100 tons. She plied from Glasgow to Inveraray by Rothesay, and was running till about 1853.

At first the early boats only plied to stations on the Clyde, such as Greenock, Helensburgh, Largs, and Rothesay—the "Dumbarton Castle," of 81 tons and 32 horse-power, built in 1815 at Dumbarton by Arch. M'Lauchlan, being the first to call at Rothesay.

In 1816 the "Britannia" was the first to run to Campbeltown, and appears also to have run a trip to Londonderry. She was the largest steamer of that time, and measured about 80 ft. long by about 16 ft. beam, and was fitted with a pair of beam engines

with spur wheels to raise the power to the paddle shaft. The cylinders were 20 ins. diameter, with 30 ins. stroke, and were made by James Cook.

In 1818 the "Rob Roy," of 90 tons and 30 horse-power, built by Wm. Denny, Dumbarton, and engined by David Napier, was the first steamer to cross to Belfast. This vessel was afterwards placed on the Dover and Calais service. The "United Kingdom," built by Mr. Steele, of Greenock, in 1826, was the first steamer to ply between Leith and London, and was also engined by Mr. D. Napier. The length of this vessel was 160 ft., there being two engines of 95 horse-power each.

The "Robert Bruce," 150 tons and 60 horse-power, and built in 1819, was the first steamer to ply from the Clyde to Liverpool.

In 1819 the "Waterloo" was built by Scott, of Greenock (this was the second vessel of that name, the first—about 70 ft. long—having been built in same year as the famous battle was fought). She measured about 120 ft. in length by 22 ft. beam, and was fitted with a pair of beam engines by James Cook, having 30 in. cylinders and 3 ft. stroke, with a spur wheel on the shaft connecting the two engines and gearing into another on the paddle shaft. The boilers were ranged on each side of the engines. This vessel plied on the route between Belfast and Liverpool.

The first steamer—with the exception already mentioned regarding the "Comet"—on the river Forth was the "Lady of the Lake," plying between Stirling and Leith. She had a single side-lever engine. This vessel was afterwards sent to ply on the Elbe in 1817.

The "Thane of Fife" and "Edinburgh Castle" were made to ply on the Burntisland ferry, and were built by J. Wood, of Port-Glasgow. The "Earl of Kellie," a larger boat, was afterwards built by Mr. Menzies, of Leith.

In 1816 a pair of engines were sent out to the Gulf of Venice, and fitted into a boat built there, and named the "Admiral Dandalo." This Steamer sailed from Trieste to Venice, and was the first on the Mediterranean.

In 1821 the "Comet" No. 2 was built for Henry Bell and others, for the West Highland route.

She was lost in 1825 off Gourock, by collision with the steamer "Ayr," when 70 lives were lost. The hull was afterwards raised, and converted into a Lighter.

In 1825 the "Enterprize," of 500 tons and 120 horse-power, made the passage to India. She was built by Gordons & Co., on the Thames, and engined by Maudslay.

The Iron Period of steam shipbuilding dates from about 1821, when the "Aaron Manby" was made at Horsley, and put together at London.

The first iron steamer built on the Clyde was the "Aglaia," in 1827. She was of 30 tons, and plied on Loch Eck.

The first iron steamer to ply on the Clyde was the "Fairie Queen," of 39 tons, built at the Old Basin, and brought down to the River and launched in 1831. This vessel plied to Largs about 1836.

The substitution of iron for wood was, however, tried at an earlier date, as the "Vulcan," built of iron plates, with flat bar frames, appears to have been designed by Sir John Robinson, of Edinburgh, in 1816, and was built at Faskine, on the Monkland Canal, in 1818, by Thomas Wilson. She commenced plying on the Forth and Clyde Canal as a passage boat in 1819.

The "Royal Sovereign," built in 1839, was the first iron sea-going steamer. She plied between Glasgow and Liverpool, and was built and engined by Tod & M'Gregor. The same firm afterwards built the "Royal George" and the "Princess Royal."

The first iron screw steamer built at Glasgow was the "Fire Queen," in 1845. She was of 135 tons, and 80 horse-power.

The first iron screw steamer to ply between Glasgow and New York was the "City of Glasgow," of 1609 tons; built by Tod & M'Gregor in 1859.

The first paddle steamer to cross the Atlantic from Britain was the "Sirius," built in 1837-8 by Menzies, of Leith, and engined by Wingate of Glasgow. The "Great Western," built at Bristol, also made the passage—the two arriving in New York about the same time.

In 1819, however, the steam-ship "Savannah" made the passage from America to Britain.

The oldest iron Clyde river steamers still plying are the "Inveraray Castle," built in 1839, and the "Balmoral," formerly the "Lady Brisbane," built in 1842.

The first Steam Dredger tried on the Clyde appears to have been in 1824. The Steam Hopper Barges, used instead of the Punts formerly employed, to convey away the dredged material, were introduced in 1862.

Hopper Dredgers, combining both Dredger and Hopper Barge in one, were brought out at a more recent date.

As we are now entering upon what may be called the Steel Period in the history of Shipbuilding, it may be well to notice that as far back as the year 1864 Messrs. Aitken & Mansel built two vessels, the "Banshee" and the "Susan Beirne" (No. 140), of Bessemer steel.

Within the last few years the wonderful ductility and strength of what is known as "Mild Steel," has become so recognised that our steamers and sailing vessels are now being built of it—a saving in weight of material of about 25 per cent. being effected by its use. Marine and Land Boilers are also now being made of this steel.

The "Columba," which recently replaced the well-known "Iona," is built of steel, and has steel boilers, and is our largest river boat, measuring 316 feet in length.

**(2) Forms of Vessels.**—Various forms have been from time to time adopted for the water lines of vessels. At one time the bows were full, with a long tapering afterpart—a form known as the "Cod's Head and Mackerel Tail," and which appears to resemble Poncelet's form.

The system of Chapman is more or less based on parabolic figures. Scott Russell's wave lines give fine bows, with full after-bodies, and were adopted from the trochoidal form of deep-water waves.

Rankine's Stream-line figures, designated Neoïds (or ship-like curves). A form of these named "Lissoneoïds" somewhat resemble the trochoidal forms, the latter being more hollow than the former.

The early ocean steamers of 40 feet beam, and 30 or 35 deep, were only about 200 feet in length. By degrees the increase in length was such that for the same breadth and depth the length was about 400 feet.

The "Arizona," lately built by Messrs. Elder & Co., measures 465 feet long by 46 feet broad, and 37 feet deep, the tonnage being 5300 tons. Still larger vessels are at present being built, both on the Clyde and elsewhere—notably the "Servia," building by James and George Thomson, and the "City of Rome," by the Barrow Shipbuilding Coy.

The "Great Eastern," as yet the largest steamer ever built, measures 680 ft. in length, 83 ft. broad, and 58 ft. deep—and measuring 22,500 tons. She was built on the Thames in 1857.

Besides the ordinary and well-known forms there have been many different forms tried—double vessels, cigar-shaped vessels, and at a later date circular or oval ships. As examples of the former, the "Alliance," twin saloon steamer, with centre paddle, was tried on the Clyde about 18 years ago. Previous to that, about 1840, another double steamer with centre wheel, and named the "Cigar," was tried, and afterwards laid up in the river about the Glasgow Green. The Winans' iron cigar-shaped vessel was tried about 1864. The channel steamers "Castalia" and "Calais-Douvres" are double boats.

The circular form for war-ships was first proposed by Mr. John Elder,* and in the "Livadia," designed by Admiral Popoff as a steam yacht for the Emperor of Russia, we have as it were the upper half of an ordinary ship placed on the back of a turbot-shaped raft. This vessel, built of steel, measures 235 ft. in length by 153 ft. in breadth, the draft being 6 ft. 6 in. She is propelled by 3 screw propellers of 16 ft. diameter, driven by 3 engines—each equal to 3500 horse-power.

**(3) Engines.**—The engine used in the boat tried on Dal-

* Lecture to United Service Institution, 1868.

swinton Loch had brass cylinders of 4 inches diameter, and was made by George Watt, in Edinburgh.

The engine of the "Charlotte Dundas" was horizontal and direct-acting.

The "Comet's" first engine, made by John Robertson, was condensing—of 3-horse power; the engine shaft appears to have been of cast-iron and fitted with a fly-wheel. A new engine was afterwards made, the cylinder being 12½ inches diameter.

The engines of the boats of the early period, after 1812, were of the side-lever type, having the peculiarity already mentioned, viz., that of spur wheels, to connect the engine shaft with the paddle wheels, as may still be seen on board of the "Industry."

The side-lever type of engine can also be well seen at Dumbarton Pier, where the engine of the steamer "Leven" is now placed. It was the first marine engine made by Mr. Robert Napier, in 1824.

In 1822 a steamer named the "Tartar" was placed on the Dublin and Holyhead route to carry the mails, and had a single horizontal cylinder of 3 ft. diameter, there being two pistons connected to one cross-head.

The steeple engine appears to have been invented by Mr. David Napier, and the "Clyde" was the first steamer fitted with one, about 1836.

This style of engine was much used, especially for the river steamers, and is still to be seen in several of our river boats—the river steamer "Scotia," built in 1879, being fitted with a pair of steeple engines. The earliest forms had a single piston rod, but later forms had four piston rods connected with the cross-head.

In 1844 the river steamers "Craignish Castle" and "Cardiff Castle" were built and engined by Caird & Co. They had diagonal direct-acting double engines.

This type of engine is now much used, and may be seen in the single form in some of our swiftest river boats.

The oscillating engine (in which the cylinder swings on trunnions, which serve as the steam passages) appears to have been brought out by Maudslay in 1831. In 1827 it is stated that the first iron steamer to ply on the Clyde, the "Fairie Queen," had an oscillating engine. This type of engine has been extensively used for river and sea-going boats, amongst the largest pairs of such engines being the paddle engines of the "Great Eastern," measuring 74 inches diameter with a stroke of 14 feet, and those of some of the Dublin and Holyhead Packets, which measure 78 inches diameter, with 6 feet 6 inches stroke.

Attempts have been made from time to time to substitute a direct rotatory motion in the machinery instead of the reciprocating motion of the ordinary engines, and various forms of rotatory engines have been devised, and were tried both for paddle and screw propeller boats.

Geared engines were at first used for screw propellers, but subsequently the inverted or steam-hammer type was introduced, and is now universally adopted in the form of the compound engine.

Trunk engines, introduced by Penn, have been much used in H.M. Navy.

The compound engine appears to have been tried at various times, and is said to have been in use in a steamer in America about 1834, on the Rhine in 1847, and some steamers in France were said to have been fitted with it, one in 1829 having two inclined cylinders connected with the same crank-pin, and one in 1842, which had three oscillating cylinders, two of which were about 11 inches diameter, and the third about 21 inches diameter—the pressure of the steam being 74 lbs. The first successful application of the compound engine to sea-going steamers was made by Messrs. Randolph, Elder, & Co. in 1854, in the steamer "Brandon." The first vessel of H.M. Navy to be fitted with compound screw engines was the "Constance," and constructed in 1863 by Messrs. Randolph, Elder, & Co. In this form of engine the steam enters one cylinder at a high pressure, and, after moving the piston through its stroke, escapes into one or more larger cylinders, where it does its work by direct expansion. Considerable economy results from the use of these engines, as vessels formerly consuming 4 to 5 lbs. of coal per indicated horse-power per hour had the consumpt reduced to 3 and $2\frac{1}{2}$ lbs. By the use of higher pressures and greater rates of expansion, the consumpt was gradually reduced to $2\frac{1}{2}$ and $2\frac{1}{4}$ lbs., and now about 2 lbs. and under is obtained.

**(4) Boilers.**—The earlier boilers, from the lowness of the steam pressure then in use (from 5 to 10 lbs. above the atmosphere), did not require to be of such strength as those of later periods, and of the present day, the plates of the marine boilers now in use being from 1 inch to $1\frac{1}{4}$ inches in thickness, and the pressures about 90 lbs. per square inch. The earlier boilers appear to have had a single turn-over flue, and were placed alongside the engine. The haystack boiler, having a series of vertical tubes through which the products of combustion passed to the funnel, was introduced by Mr. David Napier, and is still found the most suitable boiler for our river boats. Sea-going vessels are fitted with tubular boilers, the tubes being arranged horizontally. Boilers are also sometimes made having the water circulating through the tubes, and the smoke and gases outside.

In 1835 the steamer "Telegraph" was tried with the locomotive form of boiler and machinery. She exploded in 1836 at Helensburgh Pier.

Recently a small vessel named the "Anthracite" has crossed the Atlantic, fitted out on the Perkins' system; the steam pressure being about 300 lbs. per square inch.

Steel is now being used for the shell-plating of boilers, as from its greater strength lighter sections can be employed than when using malleable-iron.

**(5) Condensers.**—The jet condenser of Watt was the only form used at first, and is still used under certain circumstances. Surface condensation was attempted by Samuel Hall in 1831, and the surface condenser is now commonly used in our sea-going vessels, and has been more or less in use since 1862. It consists of a large number of brass tubes of about $\frac{3}{4}$-inch outside diameter, through which a stream of cold water is constantly kept circulating. In this manner the outer surfaces of the tubes are kept sufficiently cool to condense the exhaust steam thrown upon them from the engine cylinder. This condensed steam is used for feeding the boiler, and from its purity, a higher pressure can be kept in the boiler than when using the old form of condenser.

**(6) Propellers.**—The wheel form of propeller has been tried from an early period; at times as a single wheel at the stern of the vessel, as a centre wheel in twin vessels, or as side wheels, as in the ordinary paddle steamers. The float-boards were of wood, and fixed to the arms of the wheel. In 1844 an endless chain, with float-boards attached, and passing round two axle drums on each side of the vessel, was tried in the Clyde river steamer "Queen of Beauty," afterwards named the "Merlin." This arrangement did not suit, and the ordinary wheel was substituted. The feathering float was tried at different times, undergoing various improvements. The first steamers on the Clyde to be fitted with the feathering float were the "Craignish" and "Cardiff Castles," and afterwards successfully on the "Ruby," "Rothesay Castle," and "Mountaineer." Iron floats were also tried. The largest paddle wheels are those of the "Great Eastern," and are 56 ft. diameter. The use of the paddle wheel for ocean steamships may be said to have ceased with the "Scotia," built in 1862, for the Cunard Coy.; the screw propeller being found more suitable for sea-going vessels.

The screw propeller appears to have been tried at an early date, both in model boats and otherwise—a screw propeller steam vessel having been tried by Stevens at New York in 1802. Smith, Woodcroft, and Ericsson, also made early attempts, the latter in 1837, seems to have built a small screw steamer, with two screws. In 1840 an experiment was made by Capt. Kincaid, of Greenock, with a four-bladed propeller fitted in a steamboat on the Forth and Clyde Canal.

The first steamer in Britain to be fitted with a screw propeller was the "Archimedes," of 237 tons; built on the Thames in 1839, the horse-power being 90. She appears to have visited the Clyde in 1840.

The first screw ship in H.M. Navy was the "Dwarf," built of iron, 1843.

The "Great Britain," built in 1843, and the largest vessel of her time, was fitted with a screw propeller. She was about 300 feet long, with engines of 1000 horse power.

Twin screws, and even triple screws, as in the "Livadia," are now used, and the numbers and forms of the blades have undergone many variations.

Tugboats with screws at bow and stern have been successfully introduced on the Clyde within recent years.

The action of a jet of water, driven out by means of a turbine form of wheel, has been tried in H.M.S. "Waterwitch," and is known as the Ruthven propeller, and a form of horizontal propeller of novel construction was tried on a small boat on the Clyde some years ago.

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**The Author is indebted to previously published works on this subject, and to those who have furnished him with historical and other details.**

# CONTENTS.

# CATALOGUE.

## I. NAVAL ARCHITECTURE.

### WAR VESSELS.

1. **Model of "Henry Grace de Dieu,"** or "Harry Grace à Dieu," also called the "Great Harry" (on about a $\frac{1}{16}$-in. scale), full-rigged; the first vessel built for the English Royal Navy. This ship was built by Henry VIII. to replace the "Regent," which was destroyed in an engagement with the French on the 10th August, 1512. She was, therefore, probably laid down about August or September, 1512, and she appears to have been launched on 13th June, 1514. The Master Shipwright who built her, and who was probably the first Master Shipwright of the Royal Navy, was named William Bounde. She was 1000 tons burthen, and carried 700 men, viz., 349 soldiers, 301 marines, and 50 gunners. The number of guns varied at different times. Several accounts make them 122 in number, 19 brass and 103 iron; but most of them were very small, only 13 of them being, according to one authority, 9-prs. or upwards. The ship carried four masts and a bowsprit, all square-rigged. No English ship before Henry VIII.'s reign is known to have carried more than one mast.

THE LORDS OF THE ADMIRALTY.

2. **Model of the "Royal George."** 100 guns (on a $\frac{1}{4}$ in. scale). Length, 178 ft.; breadth, 51 ft. $9\frac{1}{2}$ in.; depth, 21 ft. 6 in.; tonnage, 2041. Launched in 1756, wrecked in 1782. This ship, the flag ship of Admiral Kempenfelt, was "overset at Spithead, 29th August, 1782, whilst being heeled in order to come at the pipe that leads to the well," and sank, with the Admiral and a crew of 800 men on board.

THE LORDS OF THE ADMIRALTY.

3. **Model of the "Victory."** 100 guns, rigged (on a $\frac{1}{10}$-in. scale). Length, 186 ft.; breadth, 52 ft. $4\frac{1}{2}$ in.; depth, 21 ft. 6 in.; tonnage, 2164. Launched 7th May, 1765. This vessel was the flag ship of Lord Nelson in the action of Trafalgar, on board which he caused that ever-memorable signal to be made, "England expects every man to do

his duty," and it was on the quarterdeck of this vessel that he received his mortal wound from a ball fired from the mizzen-top of the French ship "Redoutable."

THE LORDS OF THE ADMIRALTY.

4. **Model of Foretop-sail Mast,** made from Canvas of Foretop-sail Mast on the "Victory" during the Action at Trafalgar.

W. F. REES, Curator, Naval Museum, Greenwich.

5. **Model of the "Winchelsea."** Showing framing and structure. Presented to the Admiralty by King William the Fourth.

THE LORDS OF THE ADMIRALTY.

6. **Model of the "Bourdelois,"** 24 guns (on a $\frac{1}{4}$-in. scale). Length, 138 ft. 6 in.; breadth, 31 ft. 9 in.; depth, 15 ft. 1 in. Tonnage, 625. Built at Nantes in 1799. Captured from the French in 1799. Broken up at Chatham in 1804.

THE LORDS OF THE ADMIRALTY.

7. **Model of the "Gorgon."** 6 guns, 320 horse-power, paddle (on a $\frac{1}{4}$-in. scale). Length, 178 ft.; breadth, 37 ft. $6\frac{1}{2}$ in.; depth, 23 ft.; tonnage, 1111. Launched in 1837.

THE LORDS OF THE ADMIRALTY.

8. **Model of the "Terror"** (on a $\frac{1}{4}$-inch scale). Length, 102 ft. $4\frac{1}{2}$ in.; breadth, 26 ft. $11\frac{1}{2}$ in.; depth, 12 ft. $11\frac{1}{2}$ in.; tonnage, 326. Launched in 1813. Designed by Sir H. Peake. This vessel was employed in Arctic and Antarctic expeditions. In 1845 she was fitted with a screw propeller, and sailed with Sir J. Franklin's expedition, from which she never returned.

THE LORDS OF THE ADMIRALTY.

9. **Model of the "Spartan," and the "Atalanta."** 26 guns (on a $\frac{1}{4}$-in. scale). Length, 131 ft.; breadth, 40 ft. $7\frac{1}{4}$ in.; depth, 10 ft. 9 in.; tonnage, 918. Launched in August, 1841. The "Atalanta" began a homeward cruise from the West Indies in the spring of 1880, and has not since been heard of.

THE LORDS OF THE ADMIRALTY.

10. **Model of the "Eurydice."** 26 guns (on a $\frac{1}{4}$-in. scale). Length, 141 ft. 3 in.; breadth, 38 ft. 10 in.; depth, 8 ft. 9 in.; tonnage, 921. Launched in May, 1843. The "Eurydice" heeled over and sunk in a sudden squall in the Channel in the Autumn of 1877, and was raised July 1878.

THE LORDS OF THE ADMIRALTY.

**11. Model of the "Galatea" and the "Ariadne."** 26 guns, 800 horse-power (on a $\frac{1}{4}$-in. scale). Length, 280 ft.; breadth, 50 ft. $0\frac{3}{4}$ in.; depth, 19 ft. 4 in.; tonnage, 3214.

THE LORDS OF THE ADMIRALTY.

**12. Model of the "Immortalité."** 50 guns, 800 horse-power (on a $\frac{1}{4}$-inch scale). Length, 251 ft.; breadth, 52 ft. 1 in.; depth, 16 ft. 8 in.; tonnage, 3059. Laid down at Pembroke Yard in 1849 as a Sailing Ship; conversion to a Screw commenced in 1856. Launched in 1859.

THE LORDS OF THE ADMIRALTY.

**13. Model of the "Howe."** 121 guns, 1000 horse-power (on a $\frac{1}{4}$-inch scale). Length, 260 ft.; breadth, 61 ft. 1 in.; depth, 26 ft. 4 in.; tonnage, 4245. Launched at Pembroke Yard in 1860.

THE LORDS OF THE ADMIRALTY.

**14. Model of the "Inconstant."** 16 guns, 1000 horse-power (on $\frac{1}{4}$-in. scale). Length, 333 ft.; breadth, 50 ft. 1 in.; draught of water, 22 ft. forward, 24 ft. aft: tonnage, 4066. Armament—main deck, ten 9-in. rifled M.L. guns; upper deck, six 7-in. rifled M.L. guns. Launched in November, 1868.

THE LORDS OF THE ADMIRALTY.

**15. Model of the "Amazon."** 4 guns, 300 horse-power (on a $\frac{1}{8}$-inch scale). Length, 187 ft.; breadth, 36 ft.; draught of water, 13 ft. $5\frac{1}{2}$ in. forward, 16 ft. 5 in. aft.; tonnage, 1081; speed, 12·396. Launched at Pembroke Yard in May, 1865, sunk in the Channel by collision with another ship, 10th July, 1866.

THE LORDS OF THE ADMIRALTY.

**16. Model of the "Captain."** Built of iron, 6 guns, 900 horse-power (on a $\frac{1}{4}$-inch scale). Length, 320 ft.; breadth, 53 ft. 3 in.; draught, 22 ft. 6 in. forward, 23 ft. 6 in. aft; tonnage, 4272; displacement, 6950 tons; speed, 14 knots: area of midship section immersed, 1078 square feet. Built by Messrs. Laird, at Birkenhead. This vessel, with Captain Cowper Coles and hands to the number of 472 men, sunk at sea in September, 1870, 18 only being saved.

THE LORDS OF THE ADMIRALTY.

**17. Model of the "Glatton."** Twin Screw Turret Ship. Tonnage, 2709; displacement, 4900 tons. Armour, 14-in. iron and 15-in. teak on sides and turret. Engines, with

four 60-in. cylinders; 2 ft. 3 in. stroke. Speed, 12·109 knots, with 2868 indicated horse-power. Launched in 1871.

THE LORDS OF THE ADMIRALTY.

**18. Model of the "Monarch."** Built of iron, 6 guns, 1100 horse-power (on a ½-inch scale). Length, 330 ft.; breadth, 57 ft. 6 in.; draught, 22 ft. 6 in. forward, 26 ft. aft; tonnage, 5100; displacement, 8164 tons; speed, 14 knots; area of midship section immersed, 1224 square feet. Armament—four 22-ton guns in turrets, and two 100-prs. Launched at Chatham Yard in May, 1868.

THE LORDS OF THE ADMIRALTY.

**19. Model of the "Devastation."** Twin Screw Turret Ship. Tonnage, 4407; displacement, 9118 tons. Armour, 12-in. iron and 18-in. teak on sides, and 14-in. iron with 15-in. teak on turrets. Engines—Four 80-in. cylinders; 3 ft. 3 in. stroke. Speed, 13·84 knots, with 6652 indicated horse-power.

THE LORDS OF THE ADMIRALTY.

**20. Model Section of the "Devastation,"** showing structure and arrangement of frames, &c. Scale, ½ in. to 1 ft.

THE LORDS OF THE ADMIRALTY.

**21. Model of the Popoffka "Novgorod."** Russian Circular Armour-clad Vessel, designed by Admiral Popoff. Extreme diameter, 101 feet. Draught of water, 13 ft. 2 in.; displacement, 2490 tons. Engines—480 horse-power, working 6 screw propellers. Armament—two 28-ton guns, mounted in barbette tower.

THE LORDS OF THE ADMIRALTY.

**22. Model** (on a 1½-inch scale), showing a 6½-ton Gun mounted on the Iron Gun-carriage originally proposed by Captain R. A. E. Scott, R.N., for enabling heavy guns to be worked on the broadside. This plan, with some slight modifications, is that now (1868) generally adopted for all 6½, 9, and 12-ton guns in the Royal Navy.

THE LORDS OF THE ADMIRALTY.

**23. Model of Midship Section of the "Vanguard."** 80 guns (on ½-inch scale). Designed by Sir William Symonds.

THE LORDS OF THE ADMIRALTY.

**24. Model Section of a Ship** between decks (on a ½-inch scale), showing the Ports and a 6½-ton Gun in position, &c.
THE LORDS OF THE ADMIRALTY.

**25. Half Block Model of the "Powerful,"** classed as a second rate. 6 turrets; 12 guns in turrets. Length of ship, 438 ft. 9 in.; breadth, 67 ft. 6 in.; depth, 28 ft.; load draught, 26 ft. 6 in. Tonnage 9652, builders' old measurement; displacement, 13,200 tons. Illustrating the designs for, and interior arrangement of ships of war, on the combined Turret and Broadside system, proposed by the late Admiral Halsted. *Note.*—This Model is on a mahogany stand, and fitted to blocks. The starboard side shows the ship as completely constructed. The port side gives a longitudinal through section of the ship's internal arrangement.
THE SCIENCE AND ART DEPARTMENT, SOUTH KENSINGTON MUSEUM.

**26. Whole Model of "Le Sceptre."** 74-Gun French Ship-of-War. Date about 1700-1750. Full-rigged. No sails.
THE SCIENCE AND ART DEPARTMENT, SOUTH KENSINGTON MUSEUM.

**27. Model of the Frigate "Melampus."** This Model was constructed for the late John Scott (Grandfather of the Exhibitors), by French Prisoners confined at Barnstaple, in Devonshire. The Model is framed, planked, rigged, and equipped in exact facsimile. The rigging is spun of human hair.
SCOTT & Co., Shipbuilders, Greenock.

**28. Model of Sloop of War, "Prince of Wales."** Built by Messrs. John Scott & Sons for the British Government in 1803.
SCOTT & Co., Shipbuilders, Greenock.

**29. Model of the Frigate "Leander."** Built by Messrs. John Scott & Sons, in 1810.
SCOTT & Co., Shipbuilders, Greenock.

**30. Model of Steam Frigate "Greenock."** Built and engined by Scott, Sinclair, & Co., Greenock, 1848. This Vessel was one of the first Iron Frigates built for the British Government.
SCOTT & Co., Shipbuilders, Greenock.

**31. Model of Troop Ship,** for Government of India. Dimensions—Length, 300 ft.; breadth, 44 ft.; depth of hold, 25 ft. 6 in.; 3000 tons; 2000 I.H.P.
LAIRD BROS., Birkenhead Iron Works, Birkenhead.

**32. Model of "De Stier."** Dimensions—Length, 195 ft.; breadth, 38 ft.; depth, 19 ft.; 1312 tons; 2200 I.H.P. Armour-clad Twin Screw Steam Ram, for Coast Defence, carrying one turret with two 300-pounder guns. Light pole rig for signalling. Built for the Dutch Government, 1868.

LAIRD BROS., Birkenhead Iron Works, Birkenhead.

**33. Model of "Heiligerlee" and "Krokodil."** Dimensions—Length, 180 ft.; breadth, 44 ft.; depth, 11 ft. 6 in.; 1588 tons; 600 I.H.P. Armour-clad Twin Screw Light Draught Monitors, for Coast Defence, carrying one turret with two 300-pounder guns. Light pole masts for signalling. Built for the Dutch Government, 1868. Two similar Vessels, built for Argentine Government, 1875.

LAIRD BROS., Birkenhead Iron Works, Birkenhead.

**34. Half-Model "Simoon."** Troop-ship for British Government. Built of Iron, in 1849. Dimensions—Length, 246 ft.; breadth, 41 ft.; depth, 30 ft.; displacement tonnage, 2900. Engines—Horizontal Cylinders, 2 in number, 62½ in. diameter; stroke, 36 in.

R. NAPIER & SONS, Glasgow.

**35. Half-Model "Black Prince."** Armoured on Citadel amidships, with under water deck at ends. Built for the British Government in 1862. Dimensions—length, 380 ft.; breadth, 58 ft.; depth, moulded, 41 ft.; displacement tonnage, 9137. Engines—Horizontal Trunk. Cylinders, 2 in number, equal to 104 in. diameter; stroke, 48 in.

R. NAPIER & SONS, Glasgow.

**36. Half-Model "Hector."** Armoured right fore and aft, and on bulkheads at bow and stern. Built for the British Government in 1863. Dimensions—Length, 280 feet; breadth, 56 ft. 25 in.; depth of hold, 35 ft. 2 in.; displacement tonnage, 6713. Engines—Horizontal. Cylinders, 2 in number, 82 in. diameter; stroke, 48 in.

R. NAPIER & SONS, Glasgow.

**37. Half-Model "Hotspur."** Armoured on belt, inner breastwork, and fixed turret. Built for the British Government in 1870. Dimensions — Length, 235 ft.; breadth, 50 ft.; depth, moulded, 29 ft. 5 in.; displacement tonnage, 4010. Engines—Twin Screw Horizontal. Cylinders, 4 in number, 64 in. diameter; length of stroke, 33 in.

R. NAPIER & SONS, Glasgow.

38. **Half-Model "Northampton."** Armoured Citadel amidships below main deck, with armour under water deck and tanks at ends. Built for the British Government in 1877. Dimensions—Length, 280 ft.; breadth, 60 ft.; depth, moulded, 42 ft. 3 in.; displacement tonnage, 7323. Engines—Twin Screw Inverted. Cylinders, 6 in number, 54 in. diameter; length of stroke, 39 in. Boiler pressure, 60 lbs.
R. Napier & Sons, Glasgow.

39. **Half-Model "Leander," "Phaeton," and "Arethusa."** Fast Cruisers. No side armour, but a protective deck. Now building for the British Government. Dimensions—Length, 300 ft.; breadth, 46 ft.; depth moulded, 27 ft. 3 ins.; displacement tonnage, 3748. Engines—Twin Screw Horizontal Compound. Cylinders, 42 in. and 78 in. diameter; length of stroke, 48 in. Boiler pressure, 90 lbs.
R. Napier & Sons, Glasgow.

40. **Half-Model "De Buffel."** Armoured on belt, breastwork, and turret. Built for the Dutch Government in 1868. Dimensions—Length, 194 ft. 6 in.; breadth, moulded, 39 ft. 9¾in.; depth, moulded, 24 ft.; displacement tonnage, 2030. Engines—Twin Screw Horizontal Surface Condensing. Cylinders, 4 in number, 56 in. diameter; length of stroke, 24 in.
R. Napier & Sons, Glasgow.

41. **Half-Model "De Tyger."** Armoured on belt and turret. Built for the Dutch Government in 1868. Dimensions—Length, 184 ft. 6 in.; breadth moulded, 41 ft. 3 in.; depth, moulded, 11 ft. 6 in.; displacement tonnage, 1380. Engines—Twin Screw Horizontal. Cylinders, 4 in number, 30 in. diameter; length of stroke, 18 in.
R. Napier & Sons, Glasgow.

42. **Half-Model of H.M. Twin Screw Turret Ironclad "Hydra."** Built and engined by John Elder & Co. Dimensions—Length, 238 ft.; breadth, 45 ft.; depth, 18 ft. 6 in.; displacement, 3300 tons. Indicated horse-power, 1400; speed, 11½ knots.
John Elder & Co., Fairfield Works, Govan.

43. **Half-Model of H.M. Twin Screw Ironclad "Nelson."** Built and engined by John Elder & Co. Dimensions—Length, 310 ft.; breadth, 60 ft.; depth, 42 ft. 4 in.; displacement, 7300 tons. Indicated horse-power, 6000; speed, 14½ knots.
John Elder & Co., Fairfield Works, Govan.

**44. Model of H.M. "Jumna."** Whole Model of H.M.'s Indian Relief Steam Troop-ship "Jumna." Built 1866, by Palmer's Shipbuilding Company, Limited, Newcastle. Dimensions—Length 365 ft.; breadth, 48 ft. 9 in.; depth, 42 ft.; tonnage, gross, 4174; horse-power, 700 nominal; speed, 14½ knots per hour. Scale, 1-48th full size.

PALMER'S SHIPBUILDING Co., Limited, Jarrow-on-Tyne.

**45. Model of the "Medina."** Whole Model of H.M. Twin Screw Gunboat "Medina." For river service. Iron. Built by Palmer's Shipbuilding Company, Jarrow, 1876. Dimensions—Length, 110 ft.; breadth, 34 ft.; depth, 9½ ft.; horse-power, 310 indicated; armament, three 72-pounders and 2 Gatling guns; breastwork fore and aft.

PALMER'S SHIPBUILDING AND IRON Co., Jarrow-on-Tyne.

**46. Photograph of the Imperial Japanese Armourclad Corvette "Kon-go."** Dimensions—Length, 231 ft.; breadth, 40 ft. 9 in.; depth, 14 ft. 8 in.; 450 N.H.P. Built by Earle's Shipbuilding and Engineering Company, Limited.

EARLE'S SHIPBUILDING AND ENGINEERING COY., Limited.

**47. Photograph of the Chilian Ironclad "El Blanco Encalada."** Dimensions—Length 210 ft.; breadth, 45 ft. 9 in.; depth, 21 ft. 8 in.; nominal horse-power, 500; armament, six 9-inch 12½-ton guns, and two 20-pounder guns. Built by Earle's Shipbuilding and Engineering Company, Limited.

EARLE'S SHIPBUILDING AND ENGINEERING COY., Limited.

**48. Drawings of the Chilian Ironclads "Almirante Cochrane," and "El Blanco Encalada."** Dimensions—Length, 210 ft.; breadth, 45 ft. 9 in.; depth, 21 ft. 8 in.; nominal horse-power, 500; armament, six 9-inch 12½-ton guns, and two 20-pounder guns. Both built by Earle's Shipbuilding and Engineering Company, Limited.

EARLE'S SHIPBUILDING AND ENGINEERING COY., Limited.

**49. Steel Torpedo Boat.** Model of a first-class Steel Torpedo Boat. Built for the British Government. Speed attained, 22 miles per hour.

HANNA, DONALD, & WILSON, Abercorn Shipbuilding Co., Paisley.

**50. Model of a Steel Torpedo Boat.** Built for Greek Government. Speed, 15 miles per hour.

HANNA, DONALD, & WILSON, Abercorn Shipbuilding Co., Paisley.

## SAILING SHIPS.

**60. Viking Ship.** Photographs (2) of the Viking Ship, discovered January, 1880, in a tumulus at Sandefjord, Norway. The vessel is 75 ft. long, 16 broad, and has 25 ribs. According to tradition it was the tomb of a mighty king, and was supposed to contain great treasures, but, except various fittings, small boats and oars, drinking cups, and bones, &c., nothing was obtained, all the valuables having been carried off at some early date. The tumulus dates from the early part of the 9th century, so that the vessel is now considerably more than 1000 years old.
JOHN BOWERS, Writer, City Chambers.

**61. Model,** showing interior of a Wooden Merchant Ship.
LLOYD'S REGISTER OF SHIPPING, Cornhill, London.

**62. Model,** showing the Framing of the Fore-body of a Wooden Merchant Ship.
LLOYD'S REGISTER.

**63. Model,** showing the Framing of the After-body of a Wooden Merchant Ship.
LLOYD'S REGISTER.

**64. Model of a Diagonally-framed Ship.** Thomas Bilbe's System of Construction—Composite.
LLOYD'S REGISTER.

**65. Model of a Ship** Sheathed with Diagonal-doubling Plank. Sheathing according to Lloyd's Rules, 1864.
LLOYD'S REGISTER.

**66. Model** of Mr. John White's System of constructing Composite Iron and Wood Vessels.
LLOYD'S REGISTER.

**67. Model of an old Ship,** showing Framing, Deck, Beams, &c., also lower Masts and Bowsprit in place.
LLOYD'S REGISTER.

**68. Sectional Model of an Iron Vessel.**
LLOYD'S REGISTER.

**69. Drawing of a Composite Vessel,** showing the Iron Framework, and the mode of fastening the wood bottom.
LLOYD'S REGISTER.

**70. Drawings** (20), illustrating Lloyd's Rules and Regulations for Commercial Shipbuilding on Mr. J. White's Composite, or Iron and Wood System, and others.

LLOYD'S REGISTER.

**71. Model of East Indiaman "Carnatic."** Built and owned by John Scott & Sons, Greenock, 1837.

SCOTT & Co., Shipbuilders, Greenock.

**72. Models, Aberdeen Clipper Schooners "Scottish Maid," 1839, and "Nonsuch," 1842.** Dimensions—Length, 99 ft.; breadth, 19 ft. 9 in. (inside); depth, 12 ft. 7 in.; 150 tons register. The "Scottish Maid" was the first Aberdeen Clipper ever built. She was designed to run against the Paddle Steamers which had been introduced between Aberdeen and London, and Leith and London. The "Scottish Maid" and "Nonsuch," although built only of Scotch Fir, are still employed in the coasting trade from Aberdeen. The success of these Schooners was so remarkable that vessels of larger tonnage were built on the same principle.

A. HALL & Co., Aberdeen.

**73. Model Aberdeen Clipper Ship "Reindeer" of Liverpool.** Built in 1848. Dimensions—Length, 145 ft. 5 in.; breadth, 22 ft. 3 in. (inside); depth, 15 ft. 5 in.; 328 tons register.

A. HALL & Co., Aberdeen.

**74. Model Aberdeen Clipper Ship "Stornoway" of London.** Built in 1850. Dimensions—Length, 158 ft.; breadth, 25 ft. 8 in. (inside); depth, 17 ft. 8 in.; 527 tons.

A. HALL & Co., Aberdeen.

**75. Model Aberdeen Clipper Ship "Crysolite" of London.** Built in 1851. Dimensions—Length, 149 ft.; breadth, 26 ft. (inside); depth, 17 ft.; 440 tons.

A. HALL & Co., Aberdeen.

**76. Model Aberdeen Clipper Ship "Cairngorm" of London.** Built in 1853. Dimensions—Length, 193 ft.; breadth, 33 ft. (inside); depth, 20 ft.; 938 tons register.

A. HALL & Co., Aberdeen.

**77. Model Aberdeen Clipper Ship "Vision" of Liverpool.** Built in 1854. Dimensions—Length, 172 ft.; breadth, 29 ft. (inside); depth, 19 ft. 6 in.; 462 tons. The vessels, Nos. 73 to 77, were all well known in the China tea trade

before the days of Composite Tea Clippers, and, although of small tonnage, they opposed very successfully the Yankee Clippers three times their size, which had almost a monopoly of the China tea trade at that time.

A. HALL & Co., Aberdeen.

**78. Model Aberdeen Clipper Ship "Schomberg" of Liverpool.** Built for the "Black Ball Line" in 1855. Dimensions—Length, 270 ft.; breadth, 45 ft.; depth, 28 ft.; 2600 tons register. Lost on her first voyage at Cape Otway, in Australia.

A. HALL & Co., Aberdeen.

**79. Model of "City of Calcutta."** Wooden Sailing Ship, bottom sheathed with yellow metal. Dimensions—Length, 130 ft. 6 in.; breadth, 28 ft. 7 in.; depth, 20 ft. 2 in. Net register tonnage, 541 tons. To trade between Clyde and East Indies. Built at Glasgow in 1850, by Robert Barclay & Curle, for George Smith & Sons, Glasgow.

BARCLAY, CURLE, & Co., Whiteinch, Glasgow.

**80. Model of "City of Corinth."** Iron Sailing Ship. Dimensions—Length, 235 ft.; breadth, 35 ft. 6 in.; depth, 22 ft. 4 in. Gross register tonnage, 1276 tons. To trade between Clyde and East Indies. Built at Glasgow in 1870, by Barclay, Curle, & Co., for George Smith & Sons, Glasgow.

BARCLAY, CURLE, & Co., Whiteinch, Glasgow.

**81. Model of "County of Selkirk."** Four-masted Iron Sailing Ship. Dimensions—Length, 281 ft.; breadth, 40 ft. 6 in.; depth, 24 ft. Gross register tonnage, 1942 tons. Classed at Lloyd's 100 A1, under special survey. Built at Glasgow in 1878, by Barclay, Curle, & Co., for R. & J. Craig's "Counties" line of East Indian packets.

BARCLAY, CURLE, & Co., Whiteinch, Glasgow.

**82. Full-rigged Model "Taising."** Composite Tea Clipper Ship. $\frac{1}{8}$-inch scale.

CHARLES CONNELL & Co., Scotstoun.

**83. Full-rigged Model "Waterloo."** Four-masted Iron Sailing Ship. Dimensions—Length, 272 ft.; breadth, 40 ft. 3 in.; depth (hold), 24 ft. 3 in. Gross register tonnage, 1976 tons. $\frac{1}{4}$-inch scale.

CHARLES CONNELL & Co., Scotstoun.

**84. Full-rigged Model "Spindrift."** Composite Tea Clipper Ship. Winner, in 1868, of Ocean Race from Foo-choo-foo to London. Passage, 95 days 1 hour. $\frac{1}{4}$-inch scale.

CHARLES CONNELL & Co., Scotstoun.

85. **Half-Model of Sailing Ships "Lammermoor" and "Cedric the Saxon,"** of 1620 tons. "Cedric the Saxon," owned by Williamson, Milligan, & Co., of Liverpool, has made the passage from Liverpool to Calcutta in 71 days—the quickest on record.
JOHN REID & Co., Shipbuilders, Port-Glasgow.

86. **Half-Model of Ship,** about 1200 tons. (Artizans' Section.)
K. B. BROWN, 28 High Street, Dumbarton.

87. **Model of Sailing Ship.** Rigged Full Model of a Four-masted Sailing Ship. Scale, $\frac{1}{8}$ of an inch. (Artizans' Section.)
JOHN WILSON, 6 Robertson Street, Govan.

88. **Model of Four-masted Sailing Ship,** barque-rigged. Attached to the Model are various brass model furnishings, including a stern-post and propeller. (Artizans' Section.)
ROBERT DONALDSON, Blacksmith, 5 Quay, Dumbarton.

89. **Model "Ardbeg."** Wood East Indiaman. One of the largest sailing ships built on the Clyde up to 1855. Dimensions—Length, 182 ft.; breadth, 33 ft. 6 in.; depth, 21 ft. 6 in.; tonnage, 947. Built in 1855.
ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

90. **Model "Isabella Kerr."** Composite Ship. The largest sailing ship built on the Clyde up to 1864. Dimensions—Length, 214 ft.; breadth, 38 ft. 6 in.; depth, 24 ft. 2 in.; tonnage, 1415. Built in 1864. Owners—John Kerr & Co., Greenock.
ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

91. **Model "Peter Stuart."** Iron Sailing Ship. The largest ship built on the Clyde up to 1868. Dimensions—Length, 234 ft.; breadth 39 ft.; depth, 23 ft.; tonnage, gross register, 1490. Owners—Stuart & Douglas, Liverpool.
ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

92. **Model of "Thomasina MacLellan."** Iron Sailing Ship. The largest Iron Sailing Ship built on the Clyde up to 1873. Dimensions—Length, 262 ft. 6 in.; breadth, 40 ft. 7 in.; depth, 24 ft.; tonnage, gross register, 1873. Built in 1873. Owners—Thomson & Gray, Glasgow.
ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

93. **Model of "Stuart Hahnemann."** Iron Sailing Ship. The largest ship ever built on the Clyde. Dimensions—Length, 273 ft. 7 in.; breadth, 43 ft. 1 in.; depth, 23

ft. 6 in.; tonnage, gross register, 2056. Built in 1874. Owners—Stuart & Douglas, Liverpool.

ARCHD. M'MILLAN & SON, Dockyard, Dumbarton.

**94. Rigged Full Model of "Coriolanus."** Iron Clipper Ship. Dimensions—Length, 217 ft. 4 in.; breadth, 35 ft. 2 in.; depth, 20 ft.; tonnage, gross register, 1074. Built in 1876. Owners—John Patton, Jun., & Co. The model for which was awarded the first prize Gold Medal, and freedom of the City of London and of the Worshipful Company of Shipwrights, at the Competitive Exhibition of the Company, London, 1877. The property of the Worshipful Company.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**94a. Original Half-Model of "Coriolanus."**

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**95. Model of "Northern Monarch."** Iron Clipper Passenger Ship. Dimensions—Length, 227 ft. 4 in.; breadth, 36 ft. 6 in.; depth, 21 ft. 9 in.; tonnage, gross register, 1280. Built in 1875. Owners—Royal Exchange Shipping Co., Limited, London.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**96. Model of "MacMillan."** Iron Sailing Ship, having double bottom to contain 300 tons water ballast. In proportion to register tonnage, this vessel carries more dead weight cargo than any ship ever built. Dimensions—Length, 255 ft. 5 in.; breadth, 38 ft. 3 in.; depth, moulded, 24 ft. 9 in.; tonnage, gross register, 1507. Built in 1879. Owners—Archd. M'Millan & Son, Dumbarton.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**97. Model of "Buckhurst."** Iron Sailing Ship. One of the largest carrying ships ever built. Dimensions—Length, 277 ft.; breadth, 40 ft. 6 in.; depth, 24 ft.; tonnage, gross register, 1920. Built in 1880. Owners, W. R. Price & Co., London.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**98. Half-Model of Sailing Ships "Bay of Bengal" and "Bay of Biscay."** Built by John Elder & Co. Dimensions—Length, 276 ft.; breadth, 39 ft. 3 in.; depth, 24 ft. 9 in.; tonnage, 1600.

JOHN ELDER & CO., Fairfield Works, Govan.

**99. Perspective Drawing of Ship,** partly planked, done at Chatham Dockyards in 1762, by William Dixon.

NAPIER BROTHERS, Glasgow.

**100. Half-Model of Composite Ship "Thermopylæ."** Built by W. Hood & Co. of Aberdeen, for George Thompson & Co. Has made ten passages to Melbourne, the average length of which, from landing pilot to arrival in Melbourne, was 67 days. WALTER HOOD & Co., Aberdeen.

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## PADDLE STEAMERS.

**110. Original Whole Model of the Steamboat "Comet."** Built on the Clyde by J. Wood for Mr. Henry Bell, at Port-Glasgow, 1811. Dimensions—Length, 42 ft.; breadth, 11 ft.; depth, 5 ft. 6 in. In August, 1812, the steam passage boat "Comet," being the first steam vessel ever built in Europe, began to run between Glasgow, Greenock, and Helensburgh, with passengers only. She was advertised to leave the Broomielaw on Tuesdays, Thursdays, and Saturdays, at an hour suitable to the tide, and to return from Greenock on Mondays, Wednesdays, and Fridays. The fares were 4s. for the best cabin, and 3s. for the second, and no gratuities to the vessel's servants were allowed. The boat was driven by a condensing steam-engine of 4 horse-power. She had at first two sets of paddle-wheels on each side of the vessel (shown in the model). Her greatest speed was five miles per hour.
JOHN REID & Co., Shipbuilders, Port-Glasgow.

**111. Working Drawing,** by John Wood, Port-Glasgow, of the "Comet," built by him in 1811 for Henry Bell. The "Comet" was the first vessel propelled by steam that regularly traded in Europe. This drawing was presented by John Wood to R. Napier.
MRS. NAPIER, Yoker.

**112. Whole Model of the "Lord W. Bentinck,"** the first iron steamer built on the Thames. Built, in 1832, for the Honourable East India Company, for the navigation of the River Ganges. Designed and built by Messrs. Maudslay, Sons, & Field.
THE SCIENCE AND ART DEPARTMENT, SOUTH KENSINGTON MUSEUM.

**113. Full Model of Paddle Steamer "Persia."** First Iron Paddle Steamer of the Cunard Line. Built in 1856. (Artizans' Section.)
HUGH BROWN, 89 Elder Street, Govan.

**114. Whole Model of "Scotia."** Cunard Iron Paddle Steamer. Built, 1861, for the Cunard Company by R. Napier & Sons, Glasgow. Principal dimensions--Length, 366 ft.;

breadth, 47 ft. 6 in.. Tonnage, builders' measurement, 4050; load displacement, 6520 tons; horse-power, 1000 nominal. Diameter of cylinders, 100 in.; length of stroke, 12 ft. Diameter of paddle wheels, 40 ft. Size of floats, 11 ft. 6 in. by 2 ft. The "Scotia" may be said to be the last of the ocean-going paddle steamers for commercial purposes, screw propeller vessels having superseded them.

THE SCIENCE AND ART DEPARTMENT, SOUTH KENSINGTON MUSEUM.

**115. Half-Model of Steamer "Plymouth Rock,"** for Hudson River, U.S.A. Dimensions—Length, 340 ft.; breadth, 40 ft.; depth, 12 ft. 6 in.; engine, single beam; cylinder, 76 in. diameter, 12 ft. stroke; paddles, 36 ft. 10 in. diameter, 30 floats to each; boilers, two return-flues, 38 ft. long, 10 ft. 6 in. diameter. The engine burns $1\frac{5}{8}$ ton of coal per hour, with an average pressure of 25 lbs. The average speed of the vessel is 18 miles per hour.

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

**116. Model of "Quebec."** Iron Saloon Steamer, for passenger service on the River St. Lawrence. Dimensions—Length, 282 ft.; breadth, 34 ft.; depth, 11 ft. Tonnage, per builders' measure, 1,609 tons. Iron hull of the vessel fitted up at Glasgow, taken down in pieces, marked and numbered, and shipped to Montreal; put together there, engined and completed. Built in 1864 by Barclay, Curle, & Co., for the Richelieu Steam Navigation Co. of Montreal.

BARCLAY, CURLE, & Co., Whiteinch, Glasgow.

**117. Model of "Marquis of Bute."** Iron Paddle Steamer, for passenger service on the river Clyde. Dimensions—Length, 196 ft.; breadth, 18 ft.; depth, $7\frac{1}{2}$ ft., moulded. Engine, single diagonal; cylinder, 48-inch diameter × 60-inch stroke; 85 horse-power. Built and engined in 1868, at Glasgow, by Barclay, Curle, & Co., for Captain Alexander M'Lean, Rothesay.

BARCLAY, CURLE, & Co., Whiteinch, Glasgow.

**118. Model of "Princess Beatrice."** Iron Saloon Paddle Steamer, for passenger service between Southampton and Isle of Wight. Dimensions—Length, 175 ft.; breadth, 20 ft.; depth, $8\frac{3}{4}$ ft. moulded. Engines—Compound Diagonal Surface Condensing. Cylinders, 25 and 45 in. diameter, by 54 in. stroke; 90 horse-power. Built and engined at Glasgow in 1880 by Barclay, Curle, & Co., for the Southampton, Isle of Wight, and South of England Royal Mail Steam Packet Company.

BARCLAY, CURLE, & Co., Whiteinch, Glasgow.

**119. Half-Model of Paddle Steamer "Columba"** (Royal Mail, David MacBrayne's). Tonnage, 543; horse-power, 2450; speed, 18 knots.

JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**120. Half-Model of Paddle Steamer "Duchess of Edinburgh"** (South-Eastern Railway Company's). Tonnage, 850; horse-power, 2800; speed, 18 knots. For new service between Folkestone and Boulogne, and is expected to do the run under 1½ hours.

JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**121. Half-Model Paddle Steamer "Lord of the Isles."** The property of the Glasgow and Inveraray Steam Packet Co. Built by Messrs. David and William Henderson & Co. in 1877. Length, 246 ft.; breadth, 24 ft. 2 in.; depth, 9 ft. Engines—Diagonal oscillating, with a surface condenser. Cylinders, 46 in. in diameter; 5 ft. 6 in. stroke; wheels, 20 ft. 6 in. diameter; 2 haystack boilers; pressure, 45 lbs.

THE GLASGOW AND INVERARAY STEAM PACKET CO.

**122. Half-Model of Clyde Saloon Steamer "Ivanhoe,"** built, in 1880, by D. & W. Henderson.

D. & W. HENDERSON, Meadowside, Partick.

**123. Half-Model of the Clyde Passenger Paddle Steamer "Brodick Castle."**

H. M'INTYRE & Co., Merksworth, Paisley.

**124. Model of Steel Saloon Steamer "Chancellor."** Built in 1880 by Robert Chambers, Jun., Dumbarton, now plying between Helensburgh and Arrochar. Length, B.P., 200 ft.; breadth, moulded, 21 ft.; depth, moulded, 8 ft. 7 in.; mean draught, 3 ft. 3 in.; displacement, 205 tons. Speed, 19¾ miles. Engines, 860 horse-power, effective, by Matth. Paul & Co., Dumbarton.

ROBT. CHAMBERS, Jun., Shipbuilder, Dumbarton.

**125. Half-Model Iron Paddle Steam Ship "Princess of Wales,"** of the Great Eastern Railway Company's Passenger Line of Steamers employed between Harwich, Rotterdam, and Antwerp. Dimensions—Length, 264 ft.; breadth, 30 ft.; depth, 14 ft.; tonnage, 1090 tons gross. Engines—Oscillating Surface Condensing. 400 H.P., nominal. Built and engined by the London and Glasgow

Engineering and Iron Shipbuilding Company (Limited), 1878. Scale of Model, $\frac{1}{4}$ in.

LONDON AND GLASGOW ENGINEERING AND IRON SHIPBUILDING Co. (Limited).

**126. Model of "Cranborne."** Dimensions—Length, 213 ft.; breadth, 28 ft.; depth, 7 ft. 7 in.; 819 tons; 750 I.H.P. Paddle-wheel River Steamer for Passenger Service and Towing on the River Indus. Draught of water, 3 ft. 6 in.

LAIRD BROS., Birkenhead Iron Works, Birkenhead.

**127. Models of "Lily" and "Violet."** Dimensions—Length, 300 ft.; beam, 33 ft.; depth, 14 ft.; 1626 tons; 3200 I.H.P. Full-powered Steel Paddle-wheel Steamers for London and North-Western Railway's Express Passenger Service between Holyhead and Dublin. Speed, 19 knots.

LAIRD BROS., Birkenhead Iron Works, Birkenhead.

**128. Framed Picture:** Plan of "Lily" and "Violet.".

LAIRD BROS., Birkenhead Iron Works, Birkenhead.

**129. Model of Paddle Steamer "Kjobenhavn,"** 550 tons register; 200 N.H.P. Property of United Steamship Co., Copenhagen. Built by Lobnitz, Coulborn, & Co.

LOBNITZ, COULBORN, & Co., Engineers and Shipbuilders, Renfrew.

**130. Full-Model of Paddle Steamer "Thooreah."** Built for the Irrawaddy Flotilla Company. Length, between perpendiculars, 260 ft.; breadth, moulded, 34 ft.; depth, moulded, amidships, 9 ft.; depth, moulded, at ends, 7 ft. 6 in.; tonnage, B.M., 1470. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 34 and 59 in., stroke 54 in.

WM. DENNY & BROS., Dumbarton.

**130a. Full Model of Paddle Steamer "Doowoon."** Built for the Irrawaddy Flotilla Company. Length, between perpendiculars, 250 ft.; breadth, moulded, 30 ft.; depth, moulded, amidships, 9 ft.; depth, moulded, at ends, 7 ft.; tonnage, B.M., 1110. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 34 and 59 in., stroke 54 in.

WM. DENNY & BROS., Dumbarton.

**131. Model of Paddle Wheel Steamer "Hankow."** Built by A. & J. Inglis, Glasgow, for the China Navigation Company. Dimensions—Length, 308 ft.; breadth, 42 ft.; depth, 15 ft. 9 in.; gross tonnage, 3073. Beam Engine. Cylinder, 72 in. diameter; stroke, 14 ft.

A. & J. INGLIS, Engineers and Shipbuilders, Pointhouse, Glasgow.

132. **Model of Paddle Steamer "Pederneiras."** Dimensions—Length, 120 ft.; breadth, 16 ft.; depth, 5 ft. 6 in.; G.R., 145 tons. N.H.P., 45. Built for Light-draught River Service, Brazil.
NAPIER, SHANKS, & BELL, Yoker, near Glasgow.

133. **Half-Model of Paddle-Steamer** for the Clyde Passenger Trade. Dimensions—Length between perpendiculars, 260 ft.; breadth, moulded, 27 ft.; depth, moulded, 8 ft. 6 in. Scale, ¼ in. to one foot. (Artizans' Section).
ALEX. DENHOLM, Partick.

134. **Model of a Paddle Steamer in case.** (Artizans' Section.)
SAMUEL STEVENSON, Dalmuir.

135. **Model Iron Paddle Steamer "Queen."** Built for the Aberdeen, Leith, and Clyde Steam Company in 1844. Dimensions—Length, 180 ft.; breadth, 28 ft.; depth, 16 ft.: 573 tons register.
A. HALL & Co., Aberdeen.

136. **Model of Iron Paddle Steamer "Primrose,"** as built for Passenger Traffic on the Mersey. Dimensions—Length, 150 ft.; breadth, 25 ft.; depth, 10 ft. 6 in.; 365 tons register. 90 H.P. nominal. Speed, 13 miles an hour.
T. B. SEATH & Co., Shipbuilders, Rutherglen.

137. **Half-Model of Clyde River Steamer "Bonnie Doon."** Dimensions—Length, 210 ft.; breadth, 20 ft.; depth, 7 ft. 9 in.; 236 tons register. 100 H.P. nominal. Speed, 19 miles an hour.
T. B. SEATH & Co., Shipbuilders, Rutherglen.

138. **Painting of Paddle Steamer "Comet," 1812, and "Iona," 1874.**
Treasurer HAMILTON, 15 Royal Crescent, Glasgow.

139. **Model of Saloon Paddle Vessel "Albert Victor."** Now plying on the Elbe. Dimensions—Length, 231 ft.; breadth, 24·3 ft.; depth, 8·65 ft. Built, 1866.
AITKEN & MANSEL, Whiteinch, Glasgow.

140. **Half-Model of the Paddle Steam Vessels "Banshee" and "Susan Beirne."** Dimensions—Length, 252 ft.; breadth, 31 ft.; depth, 11·2 ft. Built of Bessemer Steel, and fitted with oscillating engines of 250 H.P. nominal; speed, 16 knots. Built, 1864.
AITKEN & MANSEL, Whiteinch, Glasgow.

141. **Oil Painting, Paddle Steam Vessel "John Wood."** A timber vessel, by that eminent builder, Engined by R. Napier, This vessel plied for many years on the Glasgow and Liverpool Station. Dimensions—Length, ; breadth, ; depth, . Built, 1832.
R. Mansel, Whiteinch.

142. **Oil Painting, Paddle Steam Vessel "Vanguard."** Dimensions—Length, 200 ft.; breadth, 27 ft.; depth, 16 ft. 5 in. Built, 1843. This vessel was built for, and plied long on, the Glasgow and Cork Station. She was the first iron vessel built by R. Napier in the Govan Building-yard.
R. Mansel, Whiteinch.

143. **Oil Painting of Paddle Steamer "Manchester,"** built in 1832 by Steele & Co., of Greenock. Tonnage, 385. Horse-power of engines, constructed by Caird & Co., 180.

144. **Oil Painting of Paddle Steamer "Britannia,"** the first of the Cunard Line, built by R. Duncan & Co., Greenock, 1839-40. Dimensions—Length, 206·9 ft.; breadth, 34·2 ft.; depth (hold), 22·2 ft.; tonnage, 1155 gross, 619 net register. Engines by R. Napier; 2 cylinders, 72 in. diameter, 6 ft. 10 in. stroke.
Robert Duncan & Co., Port-Glasgow.

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## SCREW STEAMERS.

149. **Whole Model ss. "Great Britain,"** fitted on the late Mr. James Lowe's plan for submerged or screw propellers, a patent for which was granted in March, 1838.
The Science and Art Department, South Kensington Museum.

150. **Half-Model of ss. "Buenos Ayrean."** Steel Screw Steamship. Moulded dimensions — Length, 385 ft.; breadth 42 ft.; depth, 34 ft. Tonnage, gross register, 4005. Cylinders, 51 in. and 88 in. diameter, and 54 in. stroke. Horse-power, nominal, 517, effective, 2900. Built on the continuous structural double-bottom and deep plate frame system for Messrs. James and Alexander Allan, Glasgow, by Wm. Denny and Bros., Dumbarton, and engined by Denny & Co., Dumbarton. She is the largest steel vessel afloat. 1880.
Wm. Denny & Bros.

**151. Half-Model of ss. "Generaal Pel."** Built for the Netherlands India Steam Navigation Company. Length between perpendiculars, 255 ft.; breadth, moulded, 31 ft. 6 ins.; depth to main deck, 18 ft. 2 ins.; depth to awning deck, 25 ft. 9 ins.; tonnage, gross register, 1204. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 34 and 60 in., stroke 39 in.

WM. DENNY & BROS., Shipbuilders, Dumbarton.

**152. Half-Model of ss. "Alfonso XII."** Built for Messrs. A. Lopez & Co. for Mail Service between Cadiz and Havanna. Length between perpendiculars, 350 ft.; breadth moulded, 38 ft.; depth moulded, 28 ft.; tonnage, gross register, 2915. Built by Wm. Denny & Brothers, and engined by David Rowan, Glasgow. Cylinders 50 and 88 in., stroke 48 in.

WM. DENNY & BROS., Dumbarton.

**153. Half-Model of ss. "Rotorua."** Built for the Union Steamship Company of New Zealand. Length between perpendiculars, 225 ft.; breadth, moulded, 27 ft.; depth moulded, 21 ft. 3 in.; tonnage, gross register, 926. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 34 and 60 in., stroke 39 in.

WM. DENNY & BROS., Dumbarton.

**154. Half-Model of ss. "Pau-Tah."** Built for Tong King Sing, Esq., for China River Service. Length between perpendiculars, 225 ft.; breadth, moulded, 34 ft.; depth, moulded, 21 ft.; tonnage, gross register, 1364. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 37½ and 65 in., stroke 36 in.

WM. DENNY & BROS., Dumbarton.

**155. Half-Model of ss. "Pretoria."** Built for the Union Steamship Company. Length between perpendiculars, 350 ft.; breadth, moulded, 40 ft.; depth, moulded, 32 ft. 6 in.; tonnage, gross register, 3198. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 50 and 86 in., stroke 54 in.

WM. DENNY & BROS., Dumbarton.

**156. Half-Model of ss. "Te-Anau."** Built for the Union Steamship Company of New Zealand. Length between perpendiculars, 270 ft.; breadth, moulded, 34 ft.; depth, moulded, 25 ft.; tonnage, gross register, 1652. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 36½ and 63 in., stroke 42 in.

WM. DENNY & BROS., Dumbarton.

**[Ha]lf-Model of ss. "Sirdhana."** Built for the British [I]ndia Steam Navigation Company. Length between perpendiculars, 310 ft.; breadth, moulded, 39 ft.; depth, moulded, 27 ft. 6 in.; tonnage, gross register, 2661. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 38 and 68 in., stroke 48 in.

WM. DENNY & BROS., Dumbarton.

[1]58. **Full Model of ss. "Clyde."** Built for the Peninsular and Oriental Steam Navigation Company. Length, between perpendiculars, 390 ft.; breadth, moulded, 42 ft.; depth, moulded, 35 ft.; tonnage, gross register, 4000. Built by Wm. Denny & Brothers, and engined by Denny & Co., Dumbarton. Cylinders 58 and 100 in., stroke, 63 in.

WM. DENNY & BROS., Dumbarton.

160. **Model of "Jorge Juan" and "Elcano."** Spanish Royal Mail Screw Steamships. Dimensions—Length, 212 ft.; breadth, 30 ft.; depth, 18 ft.; tonnage, gross register, 819. Built in 1880. Owners—Olano, Larrinaga, & Co., Liverpool. Speed, 12½ knots.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

161. **Model of "Wotonga."** Australian Mail Steamship. Dimensions—Length, 230 it.; breadth, 29 ft.; depth, 20 ft.; tonnage, gross register, 997. Owners—Australasian Steam Navigation Company (Limited). Built in 1876.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

162. **Models of "Amsterdam," "Edam," and "Zaandam."** Dutch Royal Mail Iron Screw Steamships. Dimensions—Length, 320 ft.; breadth, 39 ft.; depth, 30 ft.; tonnage, gross register, 3000. Owners—Netherlands American Steam Navigation Co., Rotterdam. Speed, 12½ knots.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

163. **Model of "Grecian Monarch," "Persian Monarch," and "Roman Monarch."** The Steel Screw Steamship "Grecian Monarch," and the Iron Screw Steamships "Persian Monarch" and "Roman Monarch," fitted with double bottoms on the longitudinal girder and bracket system for water ballast. Dimensions—Length, 360 ft.; breadth, 43 ft.; depth to shelter deck, 35 ft. 9 in.; tonnage, including shelter deck space, about 4000 tons. Owners—Royal Exchange Shipping Co., Limited, London. John Patton, Jun., & Co. Speed, 13 knots.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**164. Model of "Amerique."** French Mail Iron Screw Steamship. Dimensions—Length, 300 ft.; breadth, 36 ft. 6 in.; depth, 25 ft. 3 in.; tonnage, gross register, 2036; speed 12¾ knots. Owners—Fraissinet & Co., Marseilles. Built in 1879.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**165. Model of "Diolibah."** French Iron Screw Steamship, fitted with double bottom on the longitudinal girder and bracket system, and arranged for carrying palm oil in bulk. Dimensions—Length, 265 ft.; breadth, 36 ft. 3 in.; depth, 24 ft. 6 in.; tonnage, gross register 1606. Built in 1880. Owner—C. A. Verminck, Marseilles. Speed, 12 knots.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**166. Model of ss. "Admiral Miadulis."** Despatch and Transport Iron Screw Steamship belonging to H.M. the King of the Hellenes. Dimensions—Length, 260 ft.; breadth, 30 ft.; depth, 18 ft. 6 in.; tonnage, gross, 1172; speed, 14 knots. Built, 1875.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**167. Model of "Umberto I."** Italian Royal Mail Screw Steamship. Dimensions—Length, 360 ft.; breadth, 38 ft.; depth, 31 ft.; tonnage, gross register, 2752. Owners—Rocco, Piaggio, & Figilo, Genoa. Speed on trial, 16 knots. Built in 1878.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**168. Model of "Panormos" and "Simeto."** Italian Royal Mail Screw Steamships. Dimensions—Length, 270 ft.; breadth, 32 ft. 6 in.; depth, 24 ft.; tonnage, gross register, . . Owners—Florio & Co., Naples. Built in 1872. Speed, 12¾ knots.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**169. Model of "Reina Mercedes."** Spanish Royal Mail Screw Steamship. Dimensions—Length, 351 ft.; breadth, 38 ft.; depth, 31 ft.; tonnage, gross register, 3060. Built in 1878. Owners—Olano, Larrinago, & Co., Liverpool. Speed, 13 knots.

ARCH. M'MILLAN & SON, Dockyard, Dumbarton.

**170. Full Model ss. "City of Liverpool."** In course of construction, and intended to form one of Messrs. George Smith & Sons' "City" Line of Steamers. ¼-inch scale.

CHARLES CONNELL & Co., Scotstoun.

171. **Half-Model of the Steamships "Iberia" and "Liguria."** Built and engined by John Elder & Co., for the Pacific Steam Navigation Company. Dimensions—Length, 449 ft.; breadth, 44 ft. 6 in.; depth, 37 ft. 3 in.; tonnage, 4700. Indicated horse-power, 4100.
JOHN ELDER & Co., Fairfield Works, Govan.

172. **Half-Model of Pacific Steam Navigation Company's Vessels "Islay" and "Oroya."** Built and engined by John Elder & Co. Dimensions—Length, 286 ft.; breadth, 35 ft.; depth, 15 ft. 6 in. to main deck; tonnage, 1600 tons. Indicated horse-power, 1600.
JOHN ELDER & Co., Fairfield Works, Govan.

173. **Half-Model of ss. "Princess Marie."** Built and engined by John Elder & Co., for the Netherlands Steamship Company. Dimensions—Length, 340 ft.; breadth, 38 ft.; depth, 28 ft. 9 in.; tonnage, 2760. Indicated horse-power, 1800; speed, 13 knots.
JOHN ELDER & Co., Fairfield Works, Govan.

174. **Half-Model of Screw Hopper Barges "Mudlark," "Snipe," and "Curlew."** Built and engined by John Elder & Co., for the Bombay Port Trust. Dimensions—Length, 149 ft.; breadth, 25 ft.; depth, 12 ft.; tonnage, 300. Indicated horse-power, 220; speed, 9 knots.
JOHN ELDER & Co., Fairfield Works, Govan.

175. **Half-Model of Guion Liner "Arizona."** Built and engined by John Elder & Co. Dimensions—Length, 464 ft.; breadth, 45 ft 6 in.; depth, 37 ft. 6 in.; tonnage, 5200. Indicated horse-power, 6500; speed, 17·3 knots.
JOHN ELDER & Co., Fairfield Works, Govan.

176. **Model of Twin Screw Steamer "Conqueror."** Dimensions—Length, 122 ft.; breadth, 21 ft.; depth, 12 ft. 1 in., G.R., 184 tons. Engines—98 N.H.P. (Rankin's Patent) by Rankin & Blackmore, Greenock. Built for Clyde Shipping Co., Glasgow.
NAPIER, SHANKS, & BELL, Yoker, near Glasgow.

177. **Model of Awning-decked Screw Steamers "Soto" and "Ulloa."** Dimensions—Length, 212 ft.; breadth, 28 ft. 6 in.; depth, 22 ft. 6 in.; G.R., 1037 tons. N.H.P., 85. Dead-weight capacity, 1070 tons. Built for J. Roca & Co., Barcelona.
NAPIER, SHANKS, & BELL, Yoker, near Glasgow.

**178. Model of Twin Screw Steamer "Allowrie."** Dimensions—Length, 180 ft.; breadth, 24 ft. 6 in.; depth, 16 ft. 3 in.; G.R., 540 tons. Engines—98 N.H.P. (Rankin's Patent), by Rankin & Blackmore, Greenock. Built for Illawarra Steam Navigation Company, New South Wales.

NAPIER, SHANKS, & BELL, Yoker, near Glasgow.

**179. Model of Passenger and Cargo Steamer "Villa de Bilbao."** Dimensions—Length, 275 ft.; breadth, 34 ft. 6 in.; depth, 25 ft. 6 in.; 1610 tons B.M.; with Engines of 300 N.H.P. Built and engined by Cunliffe & Dunlop, Port-Glasgow.

CUNLIFFE & DUNLOP, Inch Works, Port-Glasgow.

**180. Model of Light-draught Passenger and Cargo Steamer "Julian de Zuluetta."** Dimensions—Length, 180 ft.; breadth, 27 ft.; depth, 11 ft.; 635 tons B.M.; with Engines of 100 N.H.P. Built and engined by Cunliffe & Dunlop, Port-Glasgow.

CUNLIFFE & DUNLOP, Inch Works, Port-Glasgow.

**181. Model ss. "Ferdinand Lesseps" and "Ville de Marseille."** Built by A. & J. Inglis, Glasgow. The property of the Compagnie Générale Transatlantique. Dimensions—Length, 350 ft.; breadth, 38 ft.; depth, 29 ft.; gross tonnage, 2714. Compound inverted Engines. Cylinders, 50 in. and 88 in.; stroke, 4 ft.

A. & J. INGLIS, Engineers and Shipbuilders, Pointhouse, Glasgow.

**182. Half-Model ss. "Pereire," and "Ville de Paris."** Built for the Cie Générale Transatlantique. 1866. Dimensions—Length, 345 ft.; breadth, 43 ft. 6 in.; depth, moulded, 29 ft. Tonnage, B.M., 3227. Engines—Inverted Surface Condensing Cylinders, 84 in. diam., 48 in. stroke.

R. NAPIER & SONS, Glasgow.

**183. Half-Model ss. "Parisian."** Built for Messrs. J. & A. Allan, in 1880, of steel, with double bottom. Dimensions—Length, 440 ft.; breadth, 46 ft.; depth, moulded, 36 ft. 2 in. Tonnage, G.R., 5500. Engines—Compound Inverted Surface Condensing. 3 Cylinders, 60 in. and 85 in. diameter; 60 in. stroke. Boiler pressure, 75 lbs.

R. NAPIER & SONS, Glasgow.

**184. Half-Model, Nos. 376 and 377.** Built for the Pacific Steam Navigation Company, in 1880, of steel. Dimensions

.—Length, 320 ft.; breadth, 40 ft.; depth, moulded, 23 ft. 8 in. to main deck; 30 ft. 11 in. to awning deck. Tonnage, G.R., 2400. Engines—Compound Inverted Surface Condensing. Cylinders, 42 in. and 80 in. diameter; 48 in. stroke. Boiler pressure, 90 lbs.

R. NAPIER & SONS, Glasgow.

185. **Model of Iron Screw Steamers "Enrique" and "Eduardo."** Dimensions—Length, 325 ft.; breadth, 35 ft.; depth, 25 ft. 6 in.; tonnage, 2300 gross; nominal horse-power, 250. Both built by Earle's Shipbuilding and Engineering Company, Limited, Hull, for Messrs. G. H. Fletcher & Co., of Liverpool, for the Havana trade.

EARLE'S SHIPBUILDING AND ENGINEERING COY., Limited.

186. **Model of ss. "Nerissa."** Whole Model of Ocean Screw Steamer "Nerissa." Built in 1877 by Palmer's Shipbuilding Co.

PALMER'S SHIPBUILDING AND IRON CO., Jarrow-on-Tyne.

187. **Model of ss. "Trent" and "Tamar."** 2912 tons register; 550 N.H.P. Property of Royal Mail Steam Packet Company, Southampton. Built by Lobnitz, Coulborn, & Co.

LOBNITZ, COULBORN, & Co., Engineers and Shipbuilders, Renfrew.

188. **Model of ss. "Ciudad de Cadiz."** 3084 tons register; 600 N.H.P. Property of Messrs. A. Lopez & Co., Barcelona. Built by Lobnitz, Coulborn, & Co.

LOBNITZ, COULBORN, & Co., Engineers and Shipbuilders. Renfrew.

189. **Model of ss. "City of Berlin."** Built in 1875 by Caird & Co., Greenock, for the Inman Steamship Co. (Limited), Liverpool. Dimensions—Length between perpendiculars, 478 ft.; beam, 44 ft.; depth, 36 ft.; gross tonnage, 5490. Has accommodation for 250 first-class passengers, and 1550 emigrants.

CAIRD & Co., Greenock.

190. **Model of Eight French Mail Steamers.** 1300 Tons Register; 300 H.P. Built and engined by Scott & Co.

SCOTT & Co., Shipbuilders, Greenock.

191. **Model of Screw Steamers "Malda" and "Madura."** 1941 Tons Register; 300 H.P. Built and engined for the British India Steam Navigation Co. (Limited) by Scott & Co.

SCOTT & Co., Shipbuilders, Greenock.

**192. Half-Model of Screw Steamer "Maestranza."** Dimensions—Length, 320 ft.; breadth, 40 ft.; and depth, 23 ft. Building (1880) for Companie Sud Americana de Vapores of Valparaiso.
JOHN REID & Co., Shipbuilders, Port-Glasgow.

**193. Model of Twin Screw Tug Steamer "Abeille."** Dimensions—Length, 118 ft.; breadth, 19 ft.; depth, 11 ft. 8 in.; 205 tons B.M.; with Engines of 100 N.H.P. Built and engined by Cunliffe & Dunlop, Port-Glasgow.
CUNLIFFE & DUNLOP, Inch Works, Port-Glasgow.

**194. Model of Screw Steamer "Jose Perez."** Built in 1879 by Robert Chambers, Jun., Dumbarton, and now trading from Spain. Length, B.P., 166 ft.; breadth, moulded, 24 ft.; depth in hold, 13 ft. 10 in.; draught, mean, 12 ft.; displacement, 910 tons. Speed, 11 knots. Engines, 336 horse-power, effective, by Matth. Paul & Co., Dumbarton.
ROBT. CHAMBERS, Jun., Shipbuilder, Dumbarton.

**195. Half-Model of ss. "Adria."** Built in 1880.
BLACKWOOD & GORDON, Port-Glasgow.

**195a. Half-Model of ss. "Valencia."** Dimensions—Length, keel and forecastle, 240·4'; breadth of beam, 32·35; depth of hold, 17·00; tonnage, under deck, 1016·95; gross tonnage, 1354·90; net register tonnage, 871·99; nominal horse-power, 120; speed at trial, 10·6 knots. Class steel, 100. A1 at Lloyd's.
BLACKWOOD & GORDON, Port-Glasgow.

**196. Framed Drawing.** Deck Plan, and longitudinal Section of Steel Screw Steamer. Built on the cellular double-bottom system for water ballast.
BLACKWOOD & GORDON, Port-Glasgow.

**197. Framed Drawing.** Rigging Plan for above.
BLACKWOOD & GORDON, Port-Glasgow.

**198. Framed Drawing.** Midship Section and Displacement Curves for above.
BLACKWOOD & GORDON, Port-Glasgow.

**199. Model of ss. "Glengyle" of Glasgow.** Dimensions—Length, 288 ft.; breadth, 33 ft.; depth of hold, 24 ft. 6 in.; tonnage, 1670. The first steamer of the Glen Line of

China Steamers. Built by the London and Glasgow Engineering and Iron Shipbuilding Company, Glasgow, in 1869.

GEO. W. CLARK, Dumbreck House.

200. **Model of Iron ss. "Glenartney,"** of the "Glen" Line Company's Clipper Screw Steamships for the China trade. Awarded the Silver Medal at the Paris Exhibition, 1878. These vessels are employed between London and China direct, *via* Suez Canal. *Note.*—This Model represents a fleet of steamers of about the following dimensions:—Length, 330 ft.; breadth, 35 ft.; depth, 25 ft.; tons, gross, 2106; horse-power, 330 nominal. Built and engined by the London and Glasgow Engineering and Iron Shipbuilding Company (Limited), 1874. Scale of Model, ¼ in.

LONDON AND GLASGOW ENGINEERING AND IRON SHIPBUILDING CO. (Limited).

201. **Half-Model of Iron Screw Steam Ships "Lake Champlain," "Lake Nepigon," and "Lake Megantic,"** of the Canada Shipping Company's "Beaver" Line of Steamers, employed between Liverpool and Montreal. The following are their dimensions:—Length, 320 ft.; breadth, 35 ft.; depth, 26 ft.; tons, gross, 2207; horse-power, 250 nominal. Built and engined by the London and Glasgow Engineering and Iron Shipbuilding Company (Limited), 1874-1875. Scale of Model, ¼ in.

LONDON AND GLASGOW ENGINEERING AND IRON SHIPBUILDING CO. (Limited).

202. **Half-Model Iron Screw Steam Ship "State of Nebraska,"** of the State Steam Ship Company's "State" Line of Steamers employed between Glasgow and New York. Dimensions—Length, 385 ft.; breadth, 43 ft.; depth, 32 ft. 6 in.; tonnage, 4200 gross; horse-power, 550 nominal. Built and engined by the London and Glasgow Engineering and Iron Shipbuilding Company (Limited), 1880. Scale of Model, ¼ in.

LONDON AND GLASGOW ENGINEERING AND IRON SHIPBUILDING CO. (Limited).

203. **Model of "Grantully Castle."** Iron Screw Steamer, brig rigged, lower masts and yards of steel. Dimensions—Length, 360 ft.; breadth, 43 ft. 9 in; depth, moulded, 32 ft. 6 in. Gross register tonnage, 3488 tons. Built with double bottom for water ballast. Classed at Lloyd's 100 A1, under special survey. Engines, compound inverted,

direct-acting; cylinders, 51 and 88 in. diameter × 57-inch stroke; 550 horse-power. Built and engined at Glasgow in 1879, by Barclay, Curle, & Co., for Donald Currie & Co., London, for Cape of Good Hope and Natal Royal Mail and Passenger Service.

DONALD CURRIE & Co., Fenchurch Street, London.

**204. Half-Model of the Screw Steamer "Fiume."** Owned by Messrs. Burrell & Sons, Glasgow.

H. M'INTYRE & Co., Merksworth, Paisley.

**205. Half-Model Steamship "Servia"** (Cunard Royal Mail). Tonnage, 8500; horse-power, 11,000; speed, 18 knots. The largest Merchant Steamer, except "Great Eastern," and built of steel. Is expected to attain the highest speed of any steamer in the Atlantic trade.

JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**206. Half-Model Steamship "Russia"** (Cunard Royal Mail). Tonnage, 2960; horse-power, 3500; speed, 15 knots.

JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**207. Half-Model Steamship "Gallia"** (Cunard Royal Mail). Tonnage, 4900; horse-power, 5300; speed, 16 knots.

JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**208. Half-Model of ss. "Malvina"** (London and Edinburgh Shipping Company's). Tonnage, 1200; horse-power, 1700; speed 14 knots. Fastest boat between Leith and London, and can do the run in 25 hours.

JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**209. Half-Model of Steamship "Thames"** (Peninsular and Oriental Steam Navigation Company's). Tonnage, 4200; horse-power, 4300; speed, 14½ knots.

JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**210. Half-Model of Steamship "Spartan"** (Union Steamship Company of Southampton). Tonnage, 3700; horse-power, 3500; speed, 15 knots.
JAMES & GEORGE THOMSON, Engineers and Shipbuilders, Clydebank.

**211. Half-Model Full-rigged Screw Steamer** ($\frac{1}{16}$ inch scale). Dimensions — Length, 400 ft.; breadth, 40 ft.; depth, 29 ft. 6 in. Nominal horse-power, 500. (Artizans' Section.)
WILLIAM STEEL, 33 Copeland Road, Govan.

**212. Model of Iron Screw Steamer "Fairy Queen,"** for Loch or River Passenger Service. Dimensions—Length, 82 ft.; breadth, 12 ft.; depth, 7 ft. 9 in.; 43 tons. 20 H.P. nominal; and speed 11 miles an hour.
T. B. SEATH & Co., Shipbuilders, Rutherglen.

**213. Full Model of Iron Screw Steamer** of 4414$\frac{14}{24}$ tons B.M., and 700 H.P., which obtained award of gold medal and £100, being first prize for ocean steamers in the Competitive Exhibition of the Worshipful Company of Shipwrights in June, 1877. Dimensions—Length between perpendiculars, 420 ft.; breadth, 46 ft.; depth (hold), 31 ft.; registered tonnage, 4620$\frac{20}{100}$; indicated horse-power, 2600. Designer, George C. Mackrow, Thames Ironworks and Shipbuilding Coy., Blackwall, London.
THE WORSHIPFUL COMPANY OF SHIPWRIGHTS, London.

**214. Half-Model of Twin Screw Vessel "Campana."** Built to Senor Mendez Patent for the River Plate Cattle Trade. Dimensions—Length, 241 ft.; breadth, 35·3 ft.; depth, 24·7 ft.; engines of 250 H.P. nominal, by David Rowan. The distinguishing feature of this vessel is the double hollow bottom, introduced with a view of obtaining stability. Built, 1873. *Note.*—Annesley long before and Heirsch since have wrought upon the same idea.
AITKEN & MANSEL, Whiteinch, Glasgow.

**215. Half-Model of fore and aft Screw Steam Vessel "Union."** Dimensions—Length, 90 ft.; breadth, 20 ft.; depth, 8·65. Engines of 45 H.P. nominal. Howden's patent arrangement. Built, 1878.
Messrs. AITKEN & MANSEL, Whiteinch, Glasgow.

## YACHTS.

**220. Full Model of the Imperial Yacht "Livadia."** Built by John Elder & Co., for the Czar of Russia. Dimensions—Length on water line, 229 ft.; length over all, 266 ft.; breadth on water line, 153 ft.; depth to rounded deck, 19 ft. 3 in.; depth to awning deck, 36 ft. 7 in.; tonnage, yacht measurement, $11{,}802\frac{6}{94}$. Indicated horse-power, 10,500.
John Elder & Co., Fairfield Works, Govan.

**221. Model Steam Yacht "Czarevna."** Length, 200 ft.; breadth, 28 ft.; with Engines of 130 nominal horse-power. Built for H.I.H. The Czarewitch of Russia.
Earle's Shipbuilding and Engineering Co. (Limited), Hull.

**222. Model of His Grace the Duke of Marlborough's Composite-built Steam and Sailing Yacht "Francesca."** Built by Earle's Shipbuilding aud Engineering Company, Limited. Dimensions—Length, 130 ft.; breadth, 23 ft.; depth, 11 ft. 9 in.
Earle's Shipbuilding and Engineering Coy., Limited.

**223. Model of Screw Yacht "Eros,"** 314 tons Thames measurement; 60 N.H.P. Property of Baron A. de Rothschild. Built by Lobnitz, Coulborn, & Co.
Lobnitz, Coulborn, & Co., Engineers and Shipbuilders, Renfrew.

**224. Model Five-ton Cutter Yacht "Finesse."** Designed for C. H. Kingsley & Co. 1877.
G. L. Watson & Co., Naval Architects, 108 West Regent Street, Glasgow.

**225. Model Ten-ton Cutter Yacht "Quiraing."** Built for Messrs. D. & T. Hill, in 1878.
G. L. Watson & Co.

**226. Model of Cutter Yacht "Vanduara,"** 90 tons. Built in 1880 for John Clark, Esq., Paisley, by Messrs. David and William Henderson & Co., Partick.
G. L. Watson & Co.

**227. Model Five-ton Centre-board Cutter Yacht "Snark."** Built for Sir Charles Gore, Bart., in 1878.
G. L. Watson & Co.

228. **Model Five-ton Cutter Yacht "Clotilde."** Built for W. Colhoun, Esq., in 1875.
G. L. Watson & Co.

229. **Model Ten-ton Cutter Yacht "Verve."** Built for Robert Wylie, Esq., in 1877.
G. L. Watson & Co.

230. **Model of the "Vril"** (Five-ton Cutter Yacht). Built for John Lawrence, Esq., in 1876.
G. L. Watson & Co.

231. **Model of the "Freak"** (5-ton Cutter Yacht). Designed for Lieut.-Colonel Langfield in 1876.
G. L. Watson & Co.

232. **Model of the "Senta"** (3-ton Cutter Yacht). Designed for R. D. Jameson, Esq.
G. L. Watson & Co.

233. **Model of the "Nora"** (5-ton Cutter Yacht). Built for R. G. Allan, Esq., in 1880.
G. L. Watson & Co.

234. **Model of the "Oithona"** (15-ton Cutter Yacht). Designed for Dr. Charles K. M'Kellar, M.D., of Sydney, N.S.W.
G. L. Watson & Co.

235. **Model 40-ton Cruising Cutter Yacht.** Designed, 1876.
G. L. Watson & Co.

236. **Model 40-ton Racing Cutter Yacht.** Designed, 1871.
G. L. Watson & Co.

237. **Model of the "Madge"** (10-ton Cutter Yacht). Built for James Coats, Esq., in 1879.
G. L. Watson & Co.

238. **Model of 250-ton Steam Yacht.** Designed, 1868.
G. L. Watson & Co.

239. **Model of 130-ton Schooner Yacht.** Designed, 1870.
G. L. Watson & Co.

240. **Design for 10-ton Cutter Yacht.** Scale, ½-inch to foot. Artizans' Section.
Robert L. Reid, Hill Place, Stirling Road, Glasgow.

## DREDGERS AND MISCELLANEOUS.

**260. Model of No. 1 Double Ladder Dredger.** Dimensions —Length, 157 ft.; breadth, 34 ft.; depth, 11 ft.; draft, about 7 ft. Altered from a Punt Loader to a Barge Loader in 1875. Number of buckets in each Ladder, 42; capacity of buckets, 7 cubic feet; eleven buckets tipped on each ladder per minute. Can dredge with ease in 30 feet depth of water.

THE CLYDE TRUSTEES.

**261. Model of No. 8 Single Ladder Dredger.** Dimensions —Length, 162 ft.; breadth, 29 ft.; depth, 11 ft. 6 in.; draft, 6 ft. 6 in. Number of buckets on Ladder, 39; capacity of buckets, 13 cubic feet; twelve buckets tipped per minute. Can dredge in 27 feet depth of water.

THE CLYDE TRUSTEES.

**262. Model Twin Screw Patent Hopper Dredger,** to carry 1500 tons spoil. Engines—150 horse-power, nominal. To dredge from 5 ft. to 35 ft. depth of water; lifting 500 tons per hour. Speed, 8 miles per hour.

WILLIAM SIMONS & Co., Renfrew.

**263. Drawing of Patent Hopper Dredger "Greenock,"** 1000 tons capacity; 100 horse-power, nominal. Capable of dredging in 30 ft. depth of water, and lifting 350 tons per hour. Speed, 8 miles per hour.

WILLIAM SIMONS & Co., Renfrew.

**264. Drawing of Hopper Steamer,** 600 tons capacity; 65 horse-power, nominal. Introduced by this firm, and thirty-five of them supplied to the Dutch Government, the Clyde Trust, the Mersey Board, the Crown Agent for the Colonies, the Australian Government, &c.

WILLIAM SIMONS & Co., Renfrew.

**265. Photographs (Ten) of Patent Hopper Dredgers** at present deepening various Ports in Europe, Canada, India, and Australia, and also now constructing, from 250 to 1500 tons hopper capacity, and to dredge from 1 to 40 ft. depth.

WILLIAM SIMONS & Co., Renfrew.

**266. Model Four Screw Patent Elevating Steamer** for transporting railway trains, passengers, goods, troops, and artillery, *to suit rise and fall of tide.*

WILLIAM SIMONS & Co., Renfrew.

**267. Model Four Screw Patent Elevating Ferry Steamer** to receive level traffic, *irrespective of the rise and fall of the tide.*

WILLIAM SIMONS & Co., Renfrew.

**268. Model of the ss. "Oxton,"** the first 4-screw Steamer afloat, showing the arrangement of the 4 screws, which can be worked below with finger and thumb. Also a **Model Patent Screw Propeller,** or **Bow-puller,** with Ring and 8 Vanes or Fins, which is a novelty. This model represents a propeller to $\frac{3}{4}$ scale 7 ft. 3 inches diameter, with 8 Vanes or Fins planted on the inside of the periphery of the Ring.—*See Advertisement.*

JAMES TAYLOR, Birkenhead.

**269. Model of Paddle Ferry Steamer "Claughton,"** plying between Liverpool and Birkenhead (Woodside Ferry). Dimensions—Length, 150 ft.; breadth, 50 ft.; depth, from upper deck to under side of keel, 14 ft.; has 11 water-tight compartments. Built by D. & W. Henderson.

CORPORATION OF BIRKENHEAD.

**270. Model of Twin Screws or Double Twin Screw Vessel "Oxton,"** plying between Liverpool and Birkenhead (Woodside Ferry). Dimensions—Length, 130 ft.; breadth 45 ft.; depth, from upper deck to under side of keel, 14 ft. Built by W. Simons & Co., Renfrew.

CORPORATION OF BIRKENHEAD.

**271. Model of Steamer for Dead-weight Cargoes.** Model illustrating present and proposed form of Steamer for dead-weight cargoes.

H. SOMERSET MACKENZIE, 4 Great St. Helen's, London.

**271a. Three Photographs of "Saturn."** Grain Storage Boat. Dimensions (of iron girder hull)—Length, 121 ft.; breadth, 28 ft.; depth, $2\frac{1}{2}$ ft. With four iron Tanks for storing grain, each $22\frac{1}{2}$ ft. diameter by $11\frac{1}{2}$ ft. deep, containing together 14,000 bushels. For use on River St. Lawrence. Iron hull and tanks fitted up at Glasgow, taken down in pieces, marked and numbered, and shipped to Montreal; put together there and completed. Built in 1875 by Barclay, Curle, & Co.

BARCLAY, CURLE, & Co., Whiteinch, Glasgow.

**272. Whole Model of the "Cleopatra" Ship;** used for conveying the Obelisk Cleopatra's Needle from Alexandria to London, 1877-78. Iron, built 1877; John Dixon and Benjamin Baker, Engineers. Length, 93 ft.; diameter, 15 ft.; draft of water, 9 ft.; metacentric height, 10·5 ft.

THE SCIENCE AND ART DEPARTMENT, SOUTH KENSINGTON MUSEUM.

**273. Section in Midships,** showing ordinary construction of an iron steamer. (Artizans' Section.)

EDWARD JOHNSON, High Street, Dumbarton.

**274. Bird's-eye View Drawing of the Shipyard and the Engine Works** of Messrs. Earle's Shipbuilding and Engineering Company, Limited, Hull.

EARLE'S SHIPBUILDING AND ENGINEERING COY., Limited.

**275. Half-Model of Twin Screw Barge "Vagliano,"** as built for the Danube and Black Sea Grain Trade. Dimensions—Length, 175 ft.; breadth, 27 ft.; depth, 6 ft. 9 in.; 276 tons. 40 H.P. nominal. Speed, 8 miles an hour.

T. B. SEATH & Co., Shipbuilders, Rutherglen.

**276. Half-Model of Steel Steam Launch "Acorn."** Dimensions—Length, 65 ft.; breadth, 6 ft.; depth 3 ft. 6 in. Speed, 16 miles an hour.

T. B. SEATH & Co., Shipbuilders, Rutherglen.

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## BOATS AND LIFEBOATS.

**280. Model of No. 6 Passenger Ferry Boat,** for Clyde Trustees.

HANNA, DONALD, & WILSON, Abercorn Shipbuilding Co., Paisley.

**281. Model of a Sailing Ship's Gig.** Length, 48 in.; breadth, 10 in.; depth, 4¼ in. Made to a scale of 2 in. to a foot. (Artizans' Section.)

DUNCAN CAMERON, 52 Holmhead Street, Glasgow.

**282. Model Boats.** Two Glass Cases with Model Boats, embracing Canoe, Racing Gig, Racing Jolly Boat, Pleasure Boat, &c.

ROBERT M'ALISTER, Boatbuilder, Dumbarton.

283. **Model of a Yacht's Steam Launch or Tender.** 30 ft., copper-fastened, clinker-built (on an inch scale). Built on the same principle as the Launch, with horizontal boilers, engines, and all necessary fittings complete. (Artizans' Section.)

THOMAS C. ORR, 18 Bogle Street, Greenock.

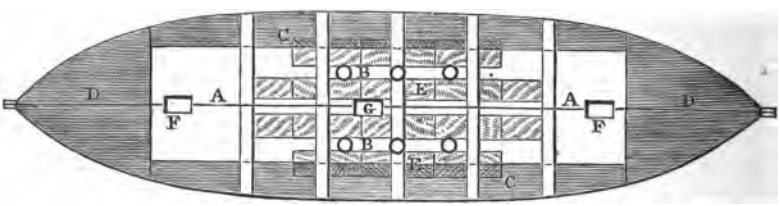
284. **Two Models of Life-boats,** exhibited by the Committee of the South Shields Library. No. 1, original Model, made by Mr. William Wouldhave, a native of South Shields. In September, 1789, the "Adventure" was driven on shore at the entrance of the river Tyne, and all hands were drowned within sight of several hundreds of persons, who were unable to save their fellow-creatures. The sad occurrence caused such an intensity of feeling that at once a number of gentlemen formed themselves into a committee, with Nicholas Fairless as the chairman, to devise some means whereby assistance might be rendered to mariners in such circumstances as overcame the ill-fated crew of the "Adventure." The said committee invited models of life-boats to be submitted to them suitable for use in shallow water and in heavy seas; and Mr. William Wouldhave made and submitted No. 1 Model, which, with another, were the only models offered. While they considered that Wouldhave's model did not embrace all the necessary qualities for the perilous duties such a craft would have to perform, they awarded him a money prize for the excellence of his model. With it as a basis, the committee designed a life-boat, Messrs. Nicholas Fairless and Michael Rockwood taking a prominent part in the work. These two gentlemen made their first model of clay at the Tile Works in their native town. No. 2 Model was the result of their experiments, and the first lifeboat was built from it, and was employed in the noble cause of rescuing a ship's crew on 30th January, 1798, being manned with a crew of that noble race of men known as South Shields Pilots. With them on such occasions ready volunteers were found to "Man the Life-boat" for the perilous task, risking their own lives in the effort to save that of their fellow-creatures, which was done without the slightest prospect of any remuneration. As originators of the lifeboat enterprise, Fairless, Rockwood, and Wouldhave stand prominently before all others.

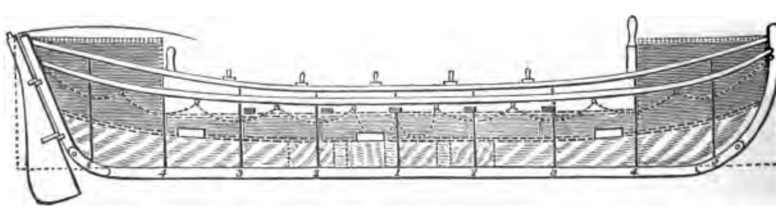
THE COMMITTEE OF THE SOUTH SHIELDS LIBRARY.

285. **Model of the Lifeboat of the Royal National Life-boat Institution,** for the Preservation of Life from Ship-

wreck on the Coasts of the British Isles. In glass case. This Lifeboat, which is 33 ft. long by 8·ft. wide, and rows ten oars double banked, possesses in the highest degree all the qualities which it is desirable that a Lifeboat should possess—1, Great lateral stability or resistance to upsetting sideways; 2, speed against a heavy sea; 3, facility for launching and taking the shore; 4, immediate self-discharge of any water breaking into it; 5, the important advantage of self-righting if upset; 6, strength; 7, stowage-room for a large number of passengers.

RICHARD LEWIS, Esq., Secretary, Royal National Lifeboat Institution, 14 John Street, Adelphi, London.

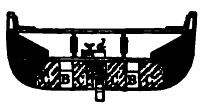


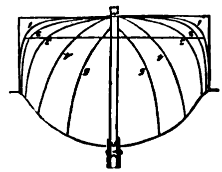



**286. Working Models of a Lifeboat of the Royal National Lifeboat Institution, and an Ordinary Ship's Boat.** Shown in tank of water. Experiments—If the Model Lifeboat be forced under water, it will at once recover itself and self-eject the water within it; and on being capsized it will immediately right itself. At the same time it will be seen that the Lifeboat has great lateral stability or resistance to upsetting sideways. On the other hand, when the small Model of a Ship's Boat is filled with water, it remains in a water-logged condition, there being no means of getting rid of any seas breaking into such a boat, except by the slow process of bailing, and when in that condition the least extra weight in the boat will sink it. Again, on its being placed on its beam-ends in the water the slightest disturbance of its equilibrium will capsize it.

These remarks apply in precisely the same manner to an ordinary large ship's boat as they do to the model.

RICHARD LEWIS, Esq., Secretary, Royal National Lifeboat Institution, 14 John Street, Adelphi, London.





**287. Cork Lifebelt,** adopted by the Royal National Lifeboat Institution of England for its Lifeboat Crews. This Lifebelt possesses sufficient extra buoyancy to support a man heavily clothed with his head and shoulders above the water, or to enable him to support another person besides himself.

RICHARD LEWIS, Esq., Secretary, Royal National Lifeboat Institution, 14 John Street, Adelphi, London.

**288. Wreck Chart of the British Isles for the Year 1876-7,** compiled from the Board of Trade Register, showing also the present Lifeboat Stations of the Royal National Lifeboat Institution.

RICHARD LEWIS, Esq., Secretary, Royal National Lifeboat Institution, 14 John Street, Adelphi, London.

**289. Model of Tyne Pilot Coble.**

R. S. ROBSON, 33 Charlotte Street, South Shields.

## II. MARINE ENGINEERING.

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### ENGINES AND PARTS OF ENGINES.

**300. "British Queen."** Book of Drawings of the Engines of the "British Queen," constructed in 1838, and of the Engines of the first Steamships of the Cunard Company, constructed, 1840, by the late Robert Napier.
ROBERT T. NAPIER (of Napier, Shanks, & Bell), Yoker.

**301. Model Pair Marine Engines, with Screw attached.**
JAMES WILSON, 17 Washington Street, Anderston, Glasgow.

**302. Model Beam Engine.**
JAMES WILSON, 17 Washington Street, Anderston, Glasgow.

**303. Model Oscillating Crank Overhead Engine.** (Artizans' Section.)
JAMES WILSON, 17 Washington Street, Anderston, Glasgow.

**304. Model of a High Pressure and Condenser Beam Engine.** (Artizans' Section.)
ROBERT WILSON, 45 Breadalbane Street, Glasgow.

**305. Design for a Four-cylinder Marine Engine** of 5000 I.H.P. The chief ends sought to be obtained in this design are—simplicity of arrangement and easy access to all parts during working, or for examination and repair; compactness, strength, and economy of manufacture. (Artizans' Section.)
JOHN IRVING, Ardeer House, Dumbarton.

**306. Model Pair of Diagonal Oscillating Engines,** 3 in. Cylinders; $4\frac{1}{2}$ in. stroke. (Artizans' Section.)
JAMES CLARK, Lugar Iron Works, Old Cumnock.

**307. Model Pair of Vertical Marine Screw Engines.** (Artizans' Section.)
ALEX. GRAY, Booth's Buildings, Brightside, Rotherham.

**308. Model Pair of Marine Engines,** with inverted Cylinders, 2 in. diameter; 2½ in. stroke; Outside Slide Valves, and Screw Starting Gear. Fitted with two lengths of Shafting and Propeller. (Artizans' Section.)
JAMES BALLANTYNE, College Park Street, Dumbarton.

**309. Model of Double Marine Engine,** with reversing Gear, &c., complete. (Artizans' Section.)
JOHN CONNER, 143 Norfolk Street, Glasgow.

**310. Working Model.** Engine and Boiler in brass.
ARCHIBALD GILCHRIST (of Barclay, Curle, & Co.), Glasgow.

**311. Engines for a Steam Launch,** with Propeller attached.
A. CAMPBELL & SON, 29 Anderston Quay, Glasgow.

**312. Small Rotary Engine.** Made by the late John Yule in 1836.
D. C. GLEN (of Glen & Ross), 21 Greenhead Street.

**313. Yacht Engines.** Dexter's Patent Yacht Engines adapted for Yachts; Winches, Hoists, Electric Machines, Winding purposes, etc.
JOHN L. DEXTER, Bourne End, near Maidenhead.

**314. Compound Engine.** Sectional Model of Kingdon's Patent Compound Engine.—*See Advertisement.*
SIMPSON & DENISON, Engineers, Dartmouth.

**315. Model of Bifurcated Piston-Rod,** showing motion of Drag Blocks in the Dual Engine.—*See Advertisement.*
H. SOMERSET MACKENZIE, 4 Great St. Helen's, London.

**316. Dual Engine.** Inverted, 8 in. cylinder, 8 in. stroke.
H. SOMERSET MACKENZIE, 4 Great St. Helen's, London.

**317. Full-size Drawing.** Section of a D shaped Cylinder and Plunger Pump, having no connecting rod or any external part. Power derived direct from steam on Piston.
H. SOMERSET MACKENZIE, 4 Great St. Helen's, London.

**318. Photos of Bifurcated Piston-Rod,** illustrating motion of Drag Block actuating concentric shafts without cog-wheel or other gear.
H. SOMERSET MACKENZIE, 4 Great St. Helen's, London.

**319. Drawings and Photos of Steam Yacht "Dua's" Engine.** 16 in. cylinder, 14 in. stroke, illustrating the motions in dual engine.
H. Somerset Mackenzie, 4 Great St. Helen's, London.

**320. Batchelor's Patent Working Diagram of Harrison Line Steamer "Inventor."** 300 H.P.
John & James Thomson, Finnieston Engine Works, Glasgow.

**321. Batchelor's Patent Working Diagram of Dominion Line Steamers "Brooklyn" and "Ottawa."** 500 H.P.
John & James Thomson, Finnieston Engine Works, Glasgow.

**322. Patent Moving Diagram Engines.** Batchelor's Patent Moving Diagram Engines of "City of Agra."
George Smith & Sons, 101 St. Vincent Street, Glasgow.

**323. Model Pair of Paddle Engines,** with oscillating cylinders. (Artizans' Section.)
James Robertson, Melville Street, Tradeston, Glasgow.

**324. Photograph of Rankin's Patent Two-Cylinder Disconnecting Compound Paddle Engines,** fitted on board paddle-steamer "Mount Etna." Queenstown Towing Co.
Rankin & Blackmore, Eagle Foundry, Greenock.

**325. Photograph of Rankin's Patent Two-Cylinder Disconnecting Compound Twin Screw Engines,** fitted on board ss. "Walrus." Port-Glasgow Towing Co.
Rankin & Blackmore, Eagle Foundry, Greenock.

**326. Model of proposed form of Rotary Engine.**
James N. Miller, 81 St. George's Place, Glasgow.

**327. Section of Pistons,** with Beverley's Improved Packing Ring and Spring for Open and Solid Head Pistons.
Robert Rankin, 35 Paisley Road.

**328. Slide Valve.** Motion for working Slide Valve and dispensing with Stuffing-box. The Model shows longitudinal section of cylinder of Steam Engine with Slide Valveand Valve-box with new Motion for connecting Slide to Excentric, dispensing with the usual Buckle, Valve Rod, and Stuffing Gland.
James Robb, Jun., 8 Carlton Place, Laurieston, Glasgow.

**329. Drawing of Simpson & Denison's Patent Combined Feed and Air Pump.**—*See Advertisement.*
SIMPSON & DENISON, Engineers, Dartmouth.

**330. King's Patent Shaft Coupling** for repairing broken Propeller Shafts at Sea. (The original Models made by the Inventors.)
Messrs. KING, 27 Frances Terrace, Victoria Park, London.

**331. Model of Piston Packing.** Buckley's Patent Compensating Piston Packing, as applied to Steam, Air, and Water Pistons.
LEES, ANDERSON, & Co., Engineers, Anderston, Glasgow.

**332. Model of Piston and Valve Rod Packing.** Cruickshank's Patent Self-acting Metallic Piston and Valve-Rod Packing.
LEES, ANDERSON, & Co., Engineers, Anderston, Glasgow.

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## BOILERS AND BOILER APPLIANCES, &c.

**340. Steel.** Various Samples of Steel used in Shipbuilding, Boiler construction, and general engineering purposes, with Tester showing qualities of metal.—*See Advertisement.*
THE LANDORE SIEMENS STEEL COMPANY (LIMITED), per CHARLES HENDERSON & Co., 9 York Street, Glasgow.

**341. Specimens of Steel Manufactures,** Plates, and Beams, &c., for Shipbuilding and Engineering purposes. Cast-steel Jaws of Punching Machine, and Cast-steel Screw Propeller.
THE STEEL COY. OF SCOTLAND (Limited), 158 Hope Street, Glasgow.

**342. Case,** containing Tests, Polished Specimens, and small Manufactures of Siemens-Martin Steel.
THE STEEL COY. OF SCOTLAND (Limited), 158 Hope Street, Glasgow.

**343. Boiler.** Model of Cochran's Patent Vertical Multitubular Boiler with Horizontal Flue Tubes.
COCHRAN & Co., Engineers, Duke Street, Birkenhead.

**344. Model of Marine Steam Boiler.** Rowan & Horton's High-pressure Water-tube Marine Steam Boiler (scale, ½ inch to the foot), as introduced in the Steamers "Haco," "Propontis," "Nepaul," "Oude," "Punjaub," "Burmah," and "Bengal." Part of the Model is in Section on a line drawn vertically through the Fire-grate.
F. J. Rowan, 15 Kelvinside Terrace.

**345. Small Copper Marine Boiler.**
The Leeds Forge Company, Leeds, Yorkshire.

**346. Set of Three Corrugated Flues,** fitted into Marine front Plate, suitable for 2 horse-power Boiler.
The Leeds Forge Company, Leeds, Yorkshire.

**348. Corrugated Galloway Tube.**
The Leeds Forge Company, Leeds, Yorkshire.

**349. Specimens of Iron and Steel,** in different stages of manufacture in Show Cases.
The Leeds Forge Company, Leeds, Yorkshire.

**350. Stand of Welded Iron Tubes,** embracing Marine Boiler Tubes, 14 in. external diameter down to 1 in.; Screwed Stay Tubes; Stanchion Tubes; Tubes, screwed and socketed; Tubes, flanged; Heating Coil; and Heating Tubes.—*See Advertisement.*
A. & J. Stewart, Clyde Tube Works, Glasgow and Coatbridge.

**351. Boiler Feed.** Conserver or Anti-corrosive Boiler Feeder (in Section).
G. & J. Weir, Engineers, 49 Jamaica Street, Glasgow.

**352. Hydrokineter and Stop and Check Valve.**
G. & J. Weir, Glasgow.

**353. Samples of Water,** showing the corrosive effect on Iron by air in solution in feed water.
G. & J. Weir, Glasgow.

**354. Perth Water Gauge Glass,** made to bear 1500 lbs. pressure per square inch.
John Moncrieff, North British Glass Works, Perth.

**355. Hydraulic Gauge Glasses,** capable of standing from 3000 to 4000 lbs. pressure per square inch.
JOHN MONCRIEFF, North British Glass Works, Perth.

**356. Hydraulic Pump** for testing Gauge Glasses.
JOHN MONCRIEFF, North British Glass Works, Perth.

**357. Series of Specimens** prepared and used in connection with the Investigations of the Admiralty Boilers' Committee.

PITTING, GROOVING, &c.

| Distinguishing Mark. | Name. | | |
|---|---|---|---|
| P. 1, | "Myrmidon," | I.C., | From bottom of the shell. |
| P. 3, | "Hector," | I.C., | From end of boiler in steam space. |
| P. 6, | "Danae," | S.C., | From back of shell in water space. |
| P. 10, | "Serapis," | S.C., | From bottom. |
| P. 25, | "Dryad," | S.C., | From back tube-plate. |
| G. 46, | "Dryad," | S.C., | From top of super-heater. |
| 54 D. 6, | "Hector," | I.C., | From top of boiler. |

DOCKYARD BOILERS.

| | | | |
|---|---|---|---|
| P. 35, | Chatham Yard, | Boiler No. 4, | Piece of plate, patch after having been on nearly 9 months. |
| P. 38, | Chatham Yard, | Boiler No. 5, | From front plate above furnace. |
| G. 52, | Chatham Yard, | Boiler No. 11, | From side of furnace, Yorkshire iron. |

LAMINATIONS.

| | | | |
|---|---|---|---|
| P. 52, | "Malabar," | S.C., | From crown of furnace. |
| P. 53, | "Nymphe," | S.C., | From side of furnace. |
| P. 54, | "Nymphe," | S.C., | Blistered piece of same. |

STAYS.

| | | | |
|---|---|---|---|
| P. 63, | "Hector," | I.C., | From up-take in steam space. |
| 54 E. 1, | "Hercules," | S.C., | Stay from boiler. |

TUBES, PIPES, &c.

| Distinguishing Mark. | Name. | | |
|---|---|---|---|
| P. 68, | "Arethusa," | S.C., | Superheater tube. |
| P. 72, | "Deccan," | | Main discharge-pipe. |
| P. 73, | "Viceroy," | | Bilge discharge-pipe. |

STEEL PLATES.

| | | |
|---|---|---|
| P. 86, | Launch No. 60, | From bottom of shell. |
| P. 88, | Flour Mill, Victoria Victualling Yard, Deptford, | Part of Flue-Boiler worked with water from the Thames; new in 1855; broken up in 1874. |

SPECIAL.

| | | |
|---|---|---|
| P. 105, | "Thunderer," | Piece of plate from the exploded boiler. |
| G. 113, | Vertical Boiler, Atlas Works, Sheffield, | From outer shell of boiler after 11 years' work. |
| P. 99, | Orange Street Water Works, London, | Piece of guard taken from air-pump bucket. |
| 1A-A2, | Hospital Boiler. | |

THE ADMIRALTY BOILERS' COMMITTEE.

**358. Morton's Automatic "Ejector-Condenser,"** suitable for a 12-in. cylinder marine or land engine, for producing a vacuum by the lateral action of a jet of water, without air-pump or moving parts.—*See Advertisement.*

ALEX. MORTON & THOMSON, Engineers, 96 Buchanan Street, Glasgow.

**359. Morton's Automatic "Ejector" or "Water-Lifter,"** for the filling or discharging of water ballast tanks on board ships, or the raising and forcing of water generally.

ALEX. MORTON & THOMSON, Engineers, 96 Buchanan Street, Glasgow.

**360. Morton's Automatic fixed Double-nozzle "Injector,"** without moving parts, for feeding water of high temperature into marine or other steam boilers.

ALEX. MORTON & THOMSON, Engineers, 96 Buchanan Street, Glasgow.

**361. Model of Lateral-Action Jet Nozzle Apparatus,** for causing the exhaust steam of high-pressure engines to produce a partial vacuum in these, and a draught in the chimneys of their boilers.

ALEX. MORTON & THOMSON, Engineers, 96 Buchanan Street, Glasgow.

**362. Sectional Drawing of "Ejector-Condenser,"** as applied to Marine Engines.

ALEX. MORTON & THOMSON, Engineers, 96 Buchanan Street, Glasgow.

**363. Sectional Drawings of "Water-Lifter" and "Injector."**—*See Advertisement.*

ALEX. MORTON & THOMSON, Engineers, 96 Buchanan Street, Glasgow.

**364. Inspirators or Boiler Feeders** (the Hancock Lifter). An apparatus which will raise water from any depth not exceeding 25 feet, and deliver it to a height not exceeding 18 feet.

JOHN DONALD & SON, 42 Cadogan Street, Glasgow.

**365. The "Hancock" Inspirator** (an improved Boiler Feeder). A new combined Pump and Injector for feeding steam boilers, raising water from wells, filling tanks, and other purposes.

JOHN DONALD & SON, 42 Cadogan Street, Glasgow.

**366. The "Hancock" Locomotive Inspirator.** Designed specially for feeding locomotive boilers.

JOHN DONALD & SON, 42 Cadogan Street, Glasgow.

**367. Series of Giffard's Injectors for feeding Boilers.** Made by Sharp, Stewart, & Coy., Limited, Atlas Works, Manchester, viz.:—

*No.* 4 *Size.*—"Atlas" Pattern Injector, entirely of brass, and having adjustment for lifting feed water.

*No.* 8 *Size.*—"Atlas" Pattern Injector, entirely of brass, without lifting arrangement, removable nozzles, &c., as above. These Injectors are specially suited for Locomotive and Traction Engines.

*No.* 5 *Size.*—Class A entirely of brass.
*No.* 10 *Size.*—Class A entirely of brass.
*No.* 3 *Size.*—Class A with cast-iron casing and brass nozzles, spindle, &c.
*Sectional* Model of Class A Injectors, showing construction of nozzles.—*See Advertisement.*
LOUDON BROTHERS, 111 Bothwell Street, Glasgow.

**368. Drawings of Justice's Steam Quieting Chambers.** These Chambers are used in connection with steam boilers of every description, and allow steam under all pressures and in any volume to pass quietly away.
JOHN DONALD & SON, 42 Cadogan Street, Glasgow.

**369. Model Apparatus for Steam Boiler Flues.** Apparatus for the front of Steam Boiler Flues, for economising Coal and preventing Smoke.
WILLIAM GORMAN, 153 West Nile Street, Glasgow.

**370. Dobson's Patent Reticulated and Perforated Furnace Bars.**
SHAW & GIBSON, 153 Queen Street, Glasgow.

**372. Model of Patent Diagonal Rocking Fire Bar.** For the better Combustion of Fuel and Prevention of Smoke.
R. T. STRANGMAN, 58 Lombard Street, London.

**373. Gresham, Steward, & Gresham's Patent Improved Giffard's Injectors,** for supplying Steam Boilers with Water.
WM. LESTER, 58 Renfield Street, Glasgow.

**374. Gresham's Patent Improved Elevators or Ejectors,** for raising Water and other Fluids or Chemicals.
WM. LESTER, 58 Renfield Street, Glasgow.

## GOVERNORS.

**380. Model of Pneumatic Marine Engine Governor.** "Dunlop's" Patent Pneumatic Marine Engine Governor for controlling the speed and preventing the racing of Engines in heavy weather.

CUNLIFFE & DUNLOP, Shipbuilders, Port-Glasgow.

**381. Model of Silver's Marine Engine Governor.**—*See Advertisement.*

WM. MURDOCH & Co., Engineers, Glasgow.

**382. Model of Weir's Patent Lever Marine Governor.**

WM. MURDOCH & Co., Engineers, Glasgow.

**383. Model of Murdoch's Patent Combined Throttle and Steam Stop Valve.**

WM. MURDOCH & Co., Engineers, Glasgow.

**384. Churchill's Patent Marine Engine Governor.** (Two Specimens.)—*See Advertisement.*

W. R. Oswald, 75 Gracechurch Street, London.

**385. Napier's Patent "Cat" Governor,** for working Throttle Valves of from 2 inches to 3 inches diameter.

NAPIER BROTHERS, Engineers, Glasgow.

**386. Robson's Patent Throttle Valve.** Drawing of Robson's Patent Trottle Valve for Governing Compound Marine Engines. Specially designed to prevent the "racing" of Compound Engines in screw steamers. The Valve can be connected to any Marine Governor, and automatically governs the Engines, and entirely prevents "racing" by its use under all circumstances. The full pressure of steam can be carried, as it only allows the steam pressure to act upon the pistons of the Engines when the propeller is in the water. It has been fitted to a great number of vessels with entire success.

H. R. ROBSON, Royal Crescent, Glasgow.

# III. EQUIPMENT.

## ANCHORS.

**400. Anchors.** Model showing new patent mode of Housing Anchors in ships' bows, dispensing with catheads, anchor davits, &c. Also new patent form of Anchor suitable for same.—*See Advertisement.*
MACNICOLL & SMITH, 6 Dixon Street, Glasgow.

**401. Anchor.** Model of Tyzack's Patent Weldless Anchor.
MACNICOLL & SMITH, 6 Dixon Street, Glasgow.

**402. Stockless Anchors.** Models of Smith's Patent Stockless Anchors, as used by the Mercantile Marine, and approved by Lloyd's and Board of Trade.
GILBERT BOGLE & Co., 47 Oswald Street, Glasgow.

**403. Stockless Anchors.** Model of Smith's Patent Stockless Anchor, as adopted by the Royal Navy. These Anchors are fluted in the arms, which increases their holding power.
GILBERT BOGLE & Co., 47 Oswald Street, Glasgow.

**404. Admiral Inglefield's Patent Double Holding Anchor.**
BROWN, LENOX, & Co., Millwall, London.

**405. Two Small Boat Anchors** (Martin's Patent).
MARTIN'S PATENT ANCHOR AND CABLE FACTORS, 101 St. Vincent Street, Glasgow.

**406. Two Small Model Anchors, in Brass** (Martin's Patent).
MARTIN'S PATENT ANCHOR FACTORS, 101 St. Vincent Street, Glasgow.

**407. Chains and Anchors.** Stand containing Models of B.B.H. Special Best Best Cables and Iron Crane Chains, pieces broken off some which have withstood enormous strains. Samples of Chains after over twenty years' wear, with Models of Anchors, including 1 Mushroom, 1 Common I.S., 1 Rodgers' I.S., 1 Rodgers' Box Stock, 1 Trotman's I.S., 1 Trotman's Box Stock, 1 Improved Trotman's Box Stock, 1 Porter's I.S., 1 Admiralty Pattern, 1 Boyce's Patent Holdfast, and a great variety of samples of iron.
H. P. PARKES & ROSS, Tipton, Staffordshire.

**408. Martin's Patent Anchors.** Model fore-section of war ship with Martin's anchors housed on one side and old Admiralty pattern on the other.
MARTIN'S Patent Anchor Factors, Glasgow.

**409. Martin's Patent Zig-zag Cable.**
MARTIN'S Patent Anchor Factors, Glasgow.

## BOAT LOWERING APPARATUS.

**410. Model of Capt. Pontet's Boat Lowering Apparatus.** By this system one man can launch a ship's boat from the inboard chocks in a few seconds. The same man lowers the boat, and another man in the boat disconnects both ends simultaneously, and the whole process of putting the boat in the water occupies only a few seconds.
COCHRAN & Co., Engineers, Birkenhead.

**411. Gear.** Models of Boats fitted with Hill & Clark's (London) Boat Disengaging Gear, and specimens of actual fittings.
RICHD. MILLER, 54 St. Enoch Square, Glasgow.

**412. Detaching Gear.** Sample & Ward's Patent Automatic Detaching Gear for Ships' Boats.
JAMES MITCHELL, 48 Gordon Street, Glasgow.

**413. Douglas' Patent Boat Lowering and Disengaging Apparatus.**—*See Advertisement.*
WM. NIMMO, 2 Oswald Street, Glasgow.

## PUMPS AND HYDRAULIC MACHINERY.

**420. A 3-inch Pumping Engine** (Invincible Vertical Direct-acting Centrifugal). Used on board Steamers for circulating water through the surface condensers, pumping from the bilges and water ballast compartments, and as a fire-engine.
JOHN & HENRY GWYNNE, Hammersmith Iron Works, London.

**421. A 3-inch Pumping Engine** (Invincible Horizontal Direct-acting Centrifugal). Used on board Steamers.
JOHN & HENRY GWYNNE, London.

422. **Framed Drawing,** showing arrangement of Gwynne's Invincible Direct-acting Pumping Engine on board Steamer.
JOHN & HENRY GWYNNE, London.

423. **Framed Drawing,** showing arrangement of Gwynne's Pumping Engine.
JOHN & HENRY GWYNNE, London.

424. **A Pumping Engine** (Invincible Direct-acting Centrifugal). Made exceedingly light, and weighing only 2 cwt. 2 qr. 21 lbs. It is capable of discharging 600 gallons of water per minute.
JOHN & HENRY GWYNNE, London.

425. **Model of Centrifugal Pump and Engine** combined, for circulating and Ballast purposes in Steamships.
DRYSDALE & PIRIE, 183 Fordneuk Street, Glasgow.

426. **Donkey Pump.** The Patent "Pendulum" Donkey Pump for Feeding Boilers, Pumping Water into Tanks at Railway Stations, Mansions, Warehouses, &c.; for Stationary Fire Engines, and for Operating Hydraulic Lifts, Cranes, Presses, &c. No. 24 size.
J. STANNAH, 20 Southwark Bridge Road, London, S.E.

427. **Patent "Pendulum" Donkey Pump.** No. 1 size.
J. STANNAH, 20 Southwark Bridge Road, London, S.E.

428. **Wilson's Patent "Clyde" Steam Pump.** The novelty of the "Clyde" Pump consists in a special arrangement of ordinary slide valves, whereby the Engine is rendered self-starting without the use of any outside gearing, and its action maintained continuously so long as steam is supplied.
DEMPSTER, MOORE, & Co., 49 Robertson Street, Glasgow.

429. **Pump and Fire-Engine.** Stone's Patent "Navy" Pump and Fire-Engine.
C. R. STEWART, 57 Robertson Street, Glasgow.

430. **Fire-Engine.** Stone's improved Portable Fire-Engine, as supplied to the principal Shipping Companies.
C. R. STEWART, 57 Robertson Street, Glasgow.

431. **Main and Bilge Pump.** Stone's improved "Simplex" Ships' Main and Bilge Pump.
C. R. STEWART, 57 Robertson Street, Glasgow.

432. **Pulsometer.** Model section of vessel's engine-room, showing Pulsometer as usually fitted-up, for emptying water ballast tanks and bilges, circulating water through condensers, washing decks and extinguishing fires.
GILBERT BOGLE & Co., 47 Oswald Street.

433. **Pulsometer.** No. 7 capable of pumping 70 tons water per hour. No. 2 capable of pumping 2000 gallons per hour.
GILBERT BOGLE & Co., 47 Oswald Street.

434. **Kinghorn & Co.'s Patent Metallic Valve.** Models representing the Metallic Valve, as applied to Air, Circulating, Bilge, Feed, and other Pumps. The Valves are made of elastic metal.
W. A. KINGHORN, 4 York Street, Glasgow.

435. **Patent Metallic Sheet Packing.** Samples of Valve Rod Packing and Pump Valves of the Patent Metallic Composition.
JOHN DONALD & SON, 42 Cadogan Street, Glasgow.

436. **Hastie's Patent Hydraulic Engine,** with cylinders 3 in. diameter by 6 in. stroke maximum.
JOHN HASTIE & Co., Kilblain Engine Works, Greenock.

437. **Working Models of Arrol's Patent Rivetting Plant.** Portable Jointed Rivetter used for the rivetting of ships' frames and keels, and for girders, &c. In nine hours this machine is capable of easily closing up 1500 rivets.
WILLIAM ARROL & Co., Dalmarnock Iron Works, Glasgow.

438. **Portable Fixed Rivetter** for open work, such as ships' beams, girders, &c. The only moving part is the piston, which carries one of the dies. It may either be hung direct to crane or hydraulic lift, thus enabling rivetting to be done both horizontally and vertically with equal facility.—*See Advertisement.*
WILLIAM ARROL & Co., Dalmarnock Iron Works, Glasgow.

439. **Runner, Traveller, and Hydraulic Lift.** The Traveller, to which the Hydraulic Lift is attached, is moved backwards and forwards, as desired, upon the runner. The Rivetter is raised and lowered by the Lift, as required. By closing the dies of Rivetter on work, the whole may be raised by Lift and run out or in as desired.
WILLIAM ARROL & Co., Dalmarnock Iron Works, Glasgow.

**470. Patent Differential Screw Bolts, Nuts, &c.** Pieces exhibiting Application of Hastie's Patent Differential Screw-Bolts, Nuts, &c.
John Hastie & Co., Kilblain Engine Works, Greenock.

**471. Model of Screw and Chain Plate** for Tightening and Slackening Rigging. Used instead of Lanyards and Dead-eyes in steam and iron sailing ships. (Artizans' Section).
James Dawson, Blacksmith, 183 Wood Crescent, Dumbarton.

**472. Purchase Blocks.** 12-inch Inside iron-bound Purchase Block.
Wm. Alexander & Co., Helen Street, Govan.

**473. Gin Sheave and Bush.** Cast-iron Sheave for Derrick, fitted with Patent Metalline Bush. This Sheave and Bush have been in use on board the ss. "Princess Royal" for upwards of 13 months, and has loaded and discharged about 33,000 tons. 1¼-inch Metalline Bush for Gin Sheave.
Wm. Alexander & Co., Helen Street, Govan.

**474. Block Sheaves.** Lignumvitae Sheave for Purchase Block, fitted with Metalline Bush, and 4 Block Sheaves, showing various Patent Bushes in use.
Wm. Alexander & Co., Helen Street, Govan.

**475. Yacht Blocks.** Inside iron-bound Yacht Blocks, showing the different kinds of bindings in common use.
Wm. Alexander & Co., Helen Street, Govan.

**476. Deadeyes.** One Upper and one lower 3-inch Lignumvitae Deadeye, shown set up as on board ship.
Wm. Alexander & Co., Helen Street, Govan.

**477. Gauges.** Assortment of Steam, Vacuum, Hydraulic, Combined, Double-dial, and Illuminated Gauges (patent).—*See Advertisement.*
Schaffer & Budenberg, 202 Hope Street, Glasgow.

**478. Counters.** Assortment of Engine Stroke and Revolution Counters (patent).
Schaffer & Budenberg, 202 Hope Street, Glasgow.

**479. Injectors.** Assortment of Injectors, new construction (patent), in iron and brass, vertical or horizontal, lifting or non-suction.
Schaffer & Budenberg, 202 Hope Street, Glasgow.

480. **Indicator.** An Engine Indicator of new construction.
SCHAFFER & BUDENBERG, 202 Hope Street, Glasgow.

481. **Thermometers.** Assortment of Thermometers, Salinometers, and Pyrometers.
SCHAFFER & BUDENBERG, 202 Hope Street, Glasgow.

482. **Pipe Unions.** Assortment of new patent Swivel Pipe Unions.
SCHAFFER & BUDENBERG, 202 Hope Street, Glasgow.

483. **Fittings.** Assortment of Engine and Boiler Fittings.
SCHAFFER & BUDENBERG, 202 Hope Street, Glasgow.

484. **Watch.** A Watchman's Watch.
SCHAFFER & BUDENBERG, 202 Hope Street, Glasgow.

485. **Governor.** A Model of the "Buss" Governor. Of this Professor Dwelshauvers Dery stated that—"In this Governor the rising and lowering of the sliding collar is effected *without friction*, and it possesses the highest perfection of a Governor—viz., Isochronism.
SCHAFFER & BUDENBERG, 202 Hope Street, Glasgow,

486. **Richards' Patent Steam Engine Indicator.** For indicating the Horse-power of Steam Engines, &c.
HANNAN & BUCHANAN, 75 Robertson Street, Glasgow.

487. **Reducing Gear.** For reducing the Stroke of the Engine down to that of the Indicator.—*See Advertisement.*
HANNAN & BUCHANAN, 75 Robertson Street, Glasgow.

488. **Engine Counter.** For showing number of Revolutions of Engine, with Marine Lever Clock combined.
HANNAN & BUCHANAN, 75 Robertson Street, Glasgow.

489. **Bourdon's Patent Steam Pressure Gauge.** For showing number of pounds per Square Inch on Boiler.
HANNAN & BUCHANAN, 75 Robertson Street, Glasgow.

490. **Bourdon's Patent Vacuum Gauge.** For showing Atmospheric Pressure on Condensers.
HANNAN & BUCHANAN, 75 Robertson Street, Glasgow.

491. **Bourdon's Patent Compound Gauge.** For showing Amount of Pressure or Vacuum in Receiver of Compound Engines.
HANNAN & BUCHANAN, 75 Robertson Street, Glasgow.

**492. Patent Organ Steam Whistle.** For Marine or other use.
HANNAN & BUCHANAN, 75 Robertson Street, Glasgow.

**493. Model of Patent Reversible Capstan or Ship's Bitts.** This Capstan can be worked either by hand, hydraulic, or steam power. It has a Gathering-in Apparatus, which renders the Machine self-acting, and is fitted with Patent Friction Cones.—*See Advertisement.*
JAMES TAYLOR, Birkenhead.

**494. Photograph of Steam Winch,** with **Windlass** combined, and Steam Sheer Legs.
JAMES TAYLOR, Birkenhead.

**495. Photograph of a 70-Ton Steam Crane,** similar to those fitted up at Stobcross Quay, Glasgow. Also **Photograph of a Steam Titan**, now being used for building the Piers of the new harbour at Colombo.
JAMES TAYLOR, Birkenhead.

**496. Working Model of an Oil Thrust Bearing for Screw Propeller Shafts,** with an arrangement for reversing the Thrust, should the vessel be propelled ahead or astern.
JAMES D. JACK, Newmill, Elgin.

**498. Winch.** Drawing of Universal Hand-power Winch.—*See Advertisement.*
H. SOMERSET MACKENZIE, 4 Great St. Helen's, London.

**499. Wire Rope Controller.** Mitchell's Patent Wire Rope Controller and Stopper. Self-adjusting, for Towing, &c.
JAMES MITCHELL, 48 Gordon Street, Glasgow.

**500. Model of Steam Winch, with Deck Pumps.** Patented in 1853.
JAMES TAYLOR, Birkenhead.

**501. Original Propeller** fitted to a long boat and experimented with in mid-ocean in 1828.
THOMAS KINCAID, Greenock.

**502. Model of Kincaid's Patent for raising and lowering Twin Screws.**
THOMAS KINCAID, Greenock.

**503. Improved Spirit Compass.**
F. MORRISON, 19 Robertson Street, Glasgow.

**504. Transparent Spirit Compass.**
F. Morrison, 19 Robertson Street, Glasgow.

**505. Sextant** (full).
F. Morrison, 19 Robertson Street, Glasgow.

**506. Two 5-inch Pressure Gauges.**
F. Morrison, 19 Robertson Street, Glasgow.

**507. Two 6-inch Vacuum Gauges.**
F. Morrison, 19 Robertson Street. Glasgow.

**508. Specimens of Leather** tanned by Heinzerlings Bichrome process. Prepared for use as deck hose, and for other marine purposes.
The Eglinton Chemical Co. (Limited), 29 St. Vincent Street, Glasgow.

**509. Electric Indicator.** Working Model of Electric Indicator as fitted to passenger steamers.
Kelso & Tod, 43 Union Street, Glasgow.

**510. Clip Hooks, &c.** Clip Hooks, Shackles, Tackle Hooks, &c., for ship's rigging.
Andrew Gill, 54 and 56 Fulbar Street, Renfrew.

**511. Patent Repeating Telegraph** between Captain and Engineer.
Mechan & Son, 118 Cheapside Street, Glasgow.

**512. Patent Repeating Telegraph** between Captain and Steersman, with Rudder Tell-tale.
Mechan & Son, 118 Cheapside Street, Glasgow.

**513. Patent Speed Indicator** for ascertaining the speed or distance travelled by steam or sailing vessels.
Mechan & Son, 118 Cheapside Street, Glasgow.

**514. Improved System of Steam Heating** for Saloons, State Rooms, &c.
Mechan & Son, 118 Cheapside Street, Glasgow.

**515. Model of Ship's Lighthouse,** with Improved Lens.
Mechan & Son, 118 Cheapside Street, Glasgow.

**516. System of Ship's Ventilation,** with Voss' Patent Updraught Ventilator.
MECHAN & SON, 118 Cheapside Street, Glasgow.

**517. Improved Fresh Water Condenser,** capable of distilling from 150 to 2000 gallons in 24 hours.
MECHAN & SON, 118 Cheapside Street, Glasgow.

**518. Boyle's Patent Air Pump Ventilators for Ships.**
R. BOYLE & SON, 110 Bothwell Street.

**519. Foghorn.** The Beck Steam Foghorn.
GILBERT BOGLE & CO., 47 Oswald Street, Glasgow.

**520. Steam Whistle.** A Compound Beck Steam Whistle, Nos. 1 and 2.
GILBERT BOGLE & CO., 47 Oswald Street, Glasgow.

**522. Telegraphs.** Stone's improved "Reply" engine-room Telegraphs, for enabling the officer in charge of a vessel to communicate his orders to the engine-room, and receive an instantaneous reply therefrom.
C. R. STEWART, 57 Robertson Street, Glasgow.

**523. Fan Blowers and Exhausters,** for Ventilating and Extracting the Foul Air from Ships' Holds and Decks.
JNO. DONALD & SON, 42 Cadogan Street, Glasgow.

**524. Joel's Patent Pneumatic Bells** for Signalling in Ships.
RICHARD MILLER, 54 St. Enoch Square, Glasgow.

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## MACHINES AND TOOLS.

**525. Ratchet Brace** on an improved principle.
JAMES MITCHELL, 48 Gordon Street, Glasgow.

**526. Steam Hammer.** Working Model of Massey's Patent Steam Hammer for the use of Marine Engineers, Iron Shipbuilders, &c.
B. & S. MASSEY, Openshaw Steam Hammer Works, Manchester.

**527. Model of 40-ton (Rigby's) Steam Hammer.** Scale, 2 in. to 1 ft.
GLEN & ROSS, Engineers, Glasgow.

**530. Case containing Illustrations of Punching with New Forms of Punch,** including a Manhole, with some of the Punches used.

CRAIG & DONALD, Johnstone.

**531. Six Framed Photographs of Machine Tools used in Shipbuilding Yards.**

CRAIG & DONALD, Johnstone.

**532. Case of Taps, &c.**—Case of Taps, Dies, Patent "Guide" Screw Stock and 2-Die Stock—new construction. Machine Taps, $\frac{1}{4}$ in. to $2\frac{1}{2}$ in.—new construction. Special Taps guaranteed to $\frac{1}{20000}$ part of an inch. Twist Drills. The penetrating power of these Drills is 100 per cent. greater than the Forged Drill generally used. Patent Twist Rhymers, for finishing holes to standard size, producing a perfectly smooth hole without jar or marking of any kind. Patent Tool Holders, for turning and planing metals, designed to establish correct cutting angles and make every tool a perfect cutter. Standard Cylindrical Gauges, correct to $\frac{1}{20000}$ part of an inch. Milling Cutters. A wrought-iron Manhole, machine-made, new. A wrought-iron Conical Tube, machine-made, new. A wrought-iron Parallel Tube, machine-made, new. A cast-steel Punching Bear and Ratchet Lever. A new Patent Oleojector, for steam lubrication. New Patent "Premier" Lubricator, for high-pressure Cylinders.—*See Advertisement.*

DAN. COCKING, 202 Hope Street, Glasgow.

**533. Hand Tools of Cast Steel.** 1 Hand Vertical, with three Drills, 2 Surface Gauges, 1 Scratch Gauge, 1 Die Stock and Spanner, 2 Spanners, 1 Shifting Tee Square, 1 Square, 1 Screw-driver, 1 pair Outside Callipers, 1 pair Inside Callipers, 1 pair Jennies and Inside Callipers combined, 1 pair Beam Compasses, 1 pair Compasses and Dividers combined, 1 Bevel Stock, 1 Centre Plum.

DAVID LOW, Blairgowrie.

**536. Case containing Engineers' Bolts and Nuts;** Deck Bolts and Nuts, Galvanised; Deck Screws; Patent Machine-made Nuts, superior to hand-made both in strength and regularity of size.—*See Advertisement.*

WM. BARWELL, Hockley Works, Birmingham.

**537. Case,** containing Samples of Manufactures in Crucible Steel for Tools, Springs, &c.; Cast-Steel Hand Struck Files; Cast-Steel Hammers, various; and Hand Tools.

Austin & Dodson, Cambria Works, Sheffield, per J. W. Jeffrey, 71A Waterloo Street, Glasgow.

# IV. NAVIGATION AND HARBOUR WORKS, &c.

550. **Parabolic Reflector,** of plated copper; used in some of the Northern Lighthouses. When the apparatus is to be cleaned the lamp is lowered out of the reflector on a sliding carriage, as arranged by the late Mr. Robert Stevenson in 1814. The object of the sliding carriage is to insure the return of the burner to the proper focus.
THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

551. **First Order Mechanical Pump Lamp.** Designed by Arago & Fresnel. As constructed for the Northern Lighthouses by Messrs. Milne & Son, Milton House, Edinburgh.
THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

552. **Catadioptric Holophote.** The light that would pass in front of the flame is parallelized by the glass Holophote, while that passing backwards is returned to the front by the spherical mirror. This apparatus was first introduced at Baccalieu, in Newfoundland, by D. & T. Stevenson, in 1858.
THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

553. **Ships' Side Light.** Mr. Thomas Stevenson's Azimuthal Condensing Ship Lights. Designed to distribute the whole light equally over ten points of the compass, in accordance with the Board of Trade requirements. Applied first in 1866 to the "Pharos" Northern Lights Steamer, and afterwards to the Anchor Line Steamers "Ethiopia" and "Bolivia."
THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

554. **Stevenson's Dioptric Holophote.** This apparatus collects all the light of the lamp into one beam of parallel rays, solely by means of glass. The apparatus constituting the front half of the instrument bends the light that falls upon it into a beam of parallel rays, while the prisms which constitute the back half are so formed as to prevent any light from passing through, and to cause every ray to

return back to the flame, and to be finally transmitted through the front half, so as to increase the intensity of the emergent beam. A large red ball is fixed on a rod, so as to be in focus to illustrate the action of the instrument. To an observer the front half of the apparatus will appear full of red light, but in the back half no red is to be seen, though the lower part of the rod which carries the ball, not being in focus, is distinctly visible. The Holophote, with improvements of Mr. J. T. Chance, was constructed by Messrs. Chance, of Birmingham.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

555. **Parabolic Reflector,** rendered Holophotal, according to Mr. Thomas Stevenson's design, by being fitted with a lens and reflecting prisms, and a portion of a spherical mirror, so as to parallelize all the light of the lamp, and to prevent the light from escaping past the lips of the reflector. Introduced in 1849.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

556. **Facet Reflector.** Formed of small facets of mirror-glass imbedded in plaster of Paris, used in the earliest of the Northern Lighthouses in 1787 till superseded by more perfect apparatus.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

557. **Model of Fresnel's First Order Fixed Dioptric Light,** one-fifth of full size. This apparatus consists of a central lenticular band, and an upper and lower set of reflecting prisms. The cylindrical belt with diagonal joints, and the upper and lower reflecting prisms were substituted by Mr. Alan Stevenson in 1836, for the segmental belt and upper and lower silvered mirrors of Fresnel's first-class apparatus.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

558. **Model of Fresnel's Revolving Apparatus,** as made for Skerryvore Lighthouse, in 1843, one-fifth of full size. The light is received and collected into eight horizontal beams by the principal lenses. The light which would escape above is collected into eight inclined beams by small lenses and reflected to the horizon by inclined mirrors. The lower part of the light is sent equally to all parts of the horizon by prismatic rings of glass, which act as mirrors. The rings at Skerryvore are the first that were made of the largest or first order size, and were undertaken by M. Soleil on the proposal of Mr. Alan Stevenson.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**559. Model of Stevenson's Holophotal Revolving Apparatus,** one-fifth of full size. The central part of this apparatus consists of eight of Fresnel's lenses. The light which passes above and below these lenses is collected into eight horizontal beams by Holophotal reflecting prisms. These reflecting prisms were substituted for the inclined lenses and mirrors of Fresnel's first order revolving apparatus by Mr. Thomas Stevenson, and were first used by him at Singapore in 1849, on a small scale, and adopted on a large scale at North Ronaldsay, in Orkney, in 1851.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**560. Stevenson's Fixed Azimuthal Condensing Light** for compressing all the light over an arc of 45°, as used at the leading lights of the River Tay. This design is remarkable from its employing every kind of dioptric apparatus. The whole of the light coming from the flame is spread equally over a horizontal arc of 45°, by means of the following instruments, viz.:—Fresnel's fixed light apparatus A, and annular lens B, and Mr. Thomas Stevenson's condensing prisms C, holophote D, right angled expanding prisms E, and double reflecting prisms F.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**561. Stevenson's Fixed Azimuthal Condensing Light,** designed by Mr. Thomas Stevenson, for sounds or narrow seas of varying width, where the light requires to be seen further off in some directions than in others, and where the whole horizon does not need to be illuminated. The light which would otherwise be wasted on the land, instead of being merely returned through the centre of the apparatus in the usual way, is gathered by refraction and prismatic reflection, and allocated in the exact proportions required for strengthening the arcs of longest range. It was first used at three Lighthouses in the Western Highlands, where small apparatus was made to produce, in those particular azimuths where alone great power is required, effects equal to much larger apparatus, consuming proportionately larger quantities of oil.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**562. Model of Stevenson's Apparent Light.**—A beam of light projected on the apparatus in the lantern A, on the beacon erected on an inaccessible rock, from a Lighthouse on the shore B, is reflected or refracted in such a manner as to indicate the position of the beacon at night. It was first

used at Stornoway, in Scotland, in 1852, and has been since used at Grangemouth and other harbours in this and in foreign countries.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

563. **Model of the Lamlash Lighthouse Apparatus, Island of Arran,** showing twin prisms A, for preventing the loss of light by absorption, and for saving room in the Lighthouse, by means of Professor Swan's mode of passing the light from the prisms behind, through the interstices between the prisms in front, described by Mr. Thomas Stevenson in "Nature," first constructed in 1876, and the new *back prisms* B, first introduced at Lochindaal Lighthouse, in Islay, in 1869.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

564. **First Order Iron Beacon for Exposed Situations,** designed by the late Mr. Alan Stevenson, LL.B., F.R.S.E.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

565. **Electric Induction Spark for Illuminating Beacons at Sea.**—The illumination of beacons by electricity was suggested by Mr. Thomas Stevenson, in 1853, and has been successfully tested by the Commissioners of Northern Lighthouses. The electricity generated on the shore is conducted by submarine wires, so as, by means of an induction coil, to produce an electric spark in the focus of optical apparatus placed on the beacon out at sea.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

566. **Stevenson's Condensing Intermittent Light,** proposed in 1872, and used at Barrahead in 1878. Straight prisms A, revolve and intercept certain of the rays from a fixed central apparatus B, so as to produce perfect darkness over the sectors they subtend, while they spread the rays which they intercept uniformly over, and thus strengthen the intermediate sectors, C, which are illuminated directly by the central apparatus. The peculiar propriety of this arrangement is that the power is increased in proportion to the duration of the intervening periods of darkness. Thus, neglecting the loss by absorption, &c., the power is *doubled* when the periods of light and darkness are *equal*, *trebled* when the dark periods are *twice* as long as the light, and so on in proportion, while in every case the rays are spread uniformly over each illuminated sector.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**567. Bell Rock Lighthouse,** situated on a reef 12 miles from Arbroath, the nearest land, and covered by 16 feet of water at high-water of spring-tides. Height of masonry 100 feet, diameter at base 42 feet, and at top 15 feet. Designed by the late Robert Stevenson, F.R.S.E., F.G.S. Commenced 1807. Finished 1811.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**568. Skerryvore Lighthouse,** situated on a reef of rocks on the West Coast of Scotland, in the Atlantic Ocean, and 10 miles from Tyree, the nearest Island. Height of masonry 138½ feet, and 42 feet in diameter at base, and 16 feet at the top. Designed by the late Alan Stevenson, LL.B., F.R.S.E. The curve of the tower is a hyperbola. Commenced 1838. Lighted 1844.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**569. Dhu Heartach Lighthouse,** situated on a rock on the West Coast of Scotland, exposed to the force of the Atlantic Ocean, and 14 miles from Iona, the nearest land. Height of masonry 107½ feet, diameter at base 36 feet, and at top 16 feet. Designed by D. & T. Stevenson. The curve of the tower is parabolic. Commenced 1867. Finished 1872.

THE COMMISSIONERS OF NORTHERN LIGHTHOUSES.

**569a. Automatic Meter for producing Intermittent Lights by the flow of Gas,** suggested in 1879 by Mr. Thomas Stevenson, and carried out by Messrs. Milne & Son, Edinburgh. The Meter is so constructed as to make the flow of the gas produce automatic intermittent action. This form of meter is made always to pass a sufficient quantity of gas to secure the constant burning of a small jet situate either immediately above or in the socket of a larger burner provided with a separate tube for giving at regular intervals an increased supply which goes to the main burner, and is there ignited by the small jet. The full flame continues to burn until the action of the meter cuts off the larger supply, and the small jet is again left burning alone. This process will, of course, go on continuously so long as the gas in the holder is not exhausted. A variety of distinctions can thus be produced in Lighthouses illuminated by gas. It seems also suitable for producing distinctions for Beacons and Buoys lighted on Pintsch's system.

The COMMISSIONERS of NORTHERN LIGHTHOUSES.

570. **Sir William Thomson's Mariners' Compass,** with Correctors for the Quadrantal Semicircular and Heeling Errors, and Azimuth Mirror for taking bearings of the Sun, Stars, or Terrestrial objects.
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

571. **Sir William Thomson's Sounding Machine,** for taking Soundings without stopping or reducing the speed of the ship.
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

572. **Sir William Thomson's Deflector,** for adjusting without sights.
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

573. **Sir William Thomson's Eclipsing Lights.**
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

574. **Sir William Thomson's Integrating Machine.**
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

575. **Marine Mercurial Barometer.**
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

576. **Aneroid Barometer.**
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

578. **Sympisometer.**
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

579. **Wet and Dry Bulb Hygrometer.**
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

580. **Maximum and Minimum Thermometer.**
JAMES WHITE, 241 Sauchiehall Street, Glasgow.

581. **A Case,** containing Eight-days' Chronometer, adjusted especially to exhibit an equal rate in extremely high temperatures, 60° to 120°. Two-days' Chronometer, adjusted to adjust rate in medium temperatures, range, 45° to 90°. Two-days' Chronometer, compensated particularly for low temperatures, 20° to 50°. Eight and Two-days'

Chronometers, exhibiting the movements in action. Eight-days' Chronometer, designed to show sidereal time for Observatory purposes. Apparatus for exposing Chronometers to various high temperatures while undergoing compensation—two Chronometers inside. Two Sextants of the best description. A Sounding Thermometer in case with valves, for showing what is the temperature of different depths of the ocean. An Engine Revolution Counter, and a few other Nautical Instruments.

D. M'GREGOR & Co., 45 Clyde Place, Glasgow, and Greenock and Liverpool.

582. **A Patent Compass and Binnacle,** by Duncan M'Gregor, F.R.G.S., embracing several valuable novelties and the results of many years' experience of ships' compasses practically considered.

D. M'GREGOR & Co., 45 Clyde Place, Glasgow, and Greenock and Liverpool.

583. **A Set of Meteorological Instruments,** as supplied gratis by D. M'Gregor & Co., in connection with the Meteorological Department of the Board of Trade, for the observation of Phenomena at Sea by Captains in the Merchant Service.

D. M'GREGOR & Co., 45 Clyde Place, Glasgow, and Greenock and Liverpool.

584. **Case,** containing 2 Marine Chronometers in ebony brass bound cases; 2 Keyless Chronograph Watches in silver cases, with independent fly-back, centre second hands; Keyless centre-second Half-Chronometer Watch in gold case, compensated for hot and cold climates; Chronometer in silver case, with black enamel dial; Chronometer in metal case; Clock, with compensation chronometer balance, striking hours and half-hours; Sextant, with bridge handle, and divided on silver to 10 seconds; 2 Marine Binocular Glasses, with aluminium frames, and 12 lenses; Miniature Binnacle and Compass; 2 Aneroid Barometers, ordinary.

F. SEWILL, 126 Broomielaw, Glasgow.

585. **Case of Chronometers, Ships' Timepieces, &c.,** comprising 2 Ships' Chronometers, one showing movement; 2 Engine-room Lever Timepieces; 2 Saloon Lever Timepieces; Lever Timepiece, Movement; Wheel-house Timepiece, double dial, showing Irish and Greenwich time;

Lever Timepiece, double 6 in. dials; Wheel-house Lever Tropmann Anchor Model, combined with lever timepiece and aneroid; Barograph and Lever Timepiece, in walnut case; 2 Aneroid Barometers; 4 Patent Engine Counters; 2 Round Engine Counters, with 7 in. dial, in brass case; Model of Engine-room Lever Timepiece, supplied for Czar's yacht "Livadia."—*See Advertisement.*

JAMES MUIRHEAD & SONS, 90 Buchanan Street, Glasgow.

**586. Chronometer Balance.** Explanation of the principles of action of the ordinary Ship Chronometer Balance, with four illustrations of the various stages of construction, from the rough casting to the finished balance, with the rim cut open to enable it to act in the variations of temperature.—*See Advertisement.*

JAMES POOLE & Co., 33 Spencer St., Clerkenwell, London.

**587. Watches.** Diagrams and Models of Keyless Mechanism for Watches.

JAMES POOLE & Co., 33 Spencer St., Clerkenwell, London.

**588. Chronometer.** Ship Chronometer (2-day) complete, with auxiliary compensation to Balance.

JAMES POOLE & Co., 33 Spencer St., Clerkenwell, London.

**589. Chronometer.** Ship Chronometer, with movement reversed to show action.

JAMES POOLE & Co., 33 Spencer St., Clerkenwell, London.

**590. Davis's Quadrant.** The precursor of the Sextant.

THOMAS DOBSON, M.A., Winterbottom Marine School, South Shields.

**591. "The Mariners' Compass Rectified."** 1 vol. London, 1758. Containing at p. 159 a figure and description of Davis's Quadrant.

THOMAS DOBSON, M.A., Winterbottom Marine School, South Shields.

**592. Deviation of the Compass.** Apparatus for illustrating lessons on the Deviation of the Compass in iron ships. A working model showing the semicircular deviations due to the permanent and induced magnetisms of the ship's hull, &c., and the usual mode of correction; quadrantal deviation,

the heeling error, the modes of determining the deviation by the dumb card, &c.

THOMAS DOBSON, M.A., Winterbottom Marine School, South Shields.

**593. Compass,** which belonged to Captain Cook, the Explorer.

THE LORDS OF THE ADMIRALTY.

**594. Dipping Needle,** which belonged to Captain Cook, the Explorer.

THE LORDS OF THE ADMIRALTY.

**595. Swing Bridge.** Two Photographs of Swing Bridge across Queen's Dock Entrance. Built by Messrs. Sir W. G. Armstrong & Co., Newcastle-on-Tyne, May, 1876.

THE CLYDE TRUSTEES.

**596. Queen's Dock Works.** Photographs of Queen's Dock Works in course of Construction, May, 1876, to August, 1879.

THE CLYDE TRUSTEES.

**597. Portrait of Henry Bell.** Age, 60. The first who brought the Steamboat into practical use. Painted by J. Tannock, 1826.

THE CLYDE TRUSTEES.

**598. Excavators.** Group of Submarine Excavators.

THE CLYDE TRUSTEES.

**599. Model of Quay Walls on Concrete Cylinders.** Queen's Dock, Glasgow, 1880.

THE CLYDE TRUSTEES.

**600. Hydraulic Coaling Crane.** Photograph of No. 1 Hydraulic Coaling Crane, North Quay, Queen's Dock, one of four erected by Messrs. Sir W. G. Armstrong & Co., June, 1878.

THE CLYDE TRUSTEES.

**601. Dredger.** Photograph of No. 1 Dredger, and attendant Barge No. 4, in course of being filled at entrance to Queen's Dock, with Diving Bell in the distance, Nov., 1875.

THE CLYDE TRUSTEES.

**602. Dredger.** Photograph of No. 1 Dredger, lying off entrance to Queen's Dock, May, 1876.
THE CLYDE TRUSTEES.

**603. Crane.** Photograph of 50-ton Steam Crane, erected by Messrs. James Taylor & Co., Birkenhead, June, 1878.
THE CLYDE TRUSTEES.

**604. Model of Caisson** for Clyde Trustees' Graving Dock, Govan.
HANNA, DONALD, & WILSON, Abercorn Shipbuilding Co., Paisley.

**605. Whole-Model of Iron Floating Dock.** Built for the French Government by Randolph, Elder, & Co., for Port Saigon, Cochin-China. Dimensions—Length, 300 ft.; breadth, 94 ft.; depth, 42 ft. Dock will lift vessel of 4800 tons weight, and 27 ft. draught of water.
JOHN ELDER & Co., Fairfield Works, Govan.

**606. Model of Kinipple's Patent Circular Dredger.**
WALTER ROBERT KINIPPLE, Whitefarland, Greenock.

**607. Models of Kinipple's Dredger Buckets,** with Interchangeable Parts.
WALTER ROBERT KINIPPLE, Whitefarland, Greenock.

**608. Model of Kinipple's Patent Travelling and Folding Bridge** to be erected across the Entrance to the West Harbour, Greenock.
WALTER ROBERT KINIPPLE, Whitefarland, Greenock.

**609. Model of Kinipple's Patent Travelling Caisson and Folding Bridge,** used at Garvel Graving Dock, Wet Dock Entrances, Monte Video Graving Dock, Quebec Graving and Wet Docks, and for the Government Graving Dock, British Columbia, &c.
WALTER ROBERT KINIPPLE, Whitefarland, Greenock.

**610. Model of Morton's Patent Slip,** for hauling Ships out of the water to be repaired, &c. The principal object of this invention is to provide a cheap substitute for Dry Docks, where it has not been thought expedient or practicable to construct them; and, both in point of economy and despatch, it has been found completely to answer the purpose for which it was originally intended.
S. & H. MORTON & Co., Leith.

611. **Blake's Patent Masthead Lamp,** Dioptric Lens, with Patent Duplex Burner, for Colza Oil.—*See Advertisement.*
Blake & Dain, Birmingham.

612. **Blake's Patent Port Lamp,** Dioptric Lens, with Patent Extinguisher Burner, for the Mineral Oils.
Blake & Dain, Birmingham.

613. **Blake's Patent Starboard Lamp,** Dioptric Lens, with Patent Extinguisher Burner, for the Mineral Oils.
Blake & Dain, Birmingham.

614. **Blake's Patent Anchor Lamp,** plain Globe, with Patent Duplex Burner, for the Mineral Oils.
Blake & Dain, Birmingham.

615. **Blake's Patent Anchor Lamp,** plain Globe, with Patent Single-flame Burner, for the Mineral Oils.
Blake & Dain, Birmingham.

616. **Blake's Patent Engine-room Lamp,** with Patent Single-flame Burner, for the Mineral Oils.
Blake & Dain, Birmingham.

617. **Ships' and Harbour Lamps,** as follows:—Masthead Lamp (Chimneyless); Portside Lamp (Chimneyless); Starboardside Lamp (Chimneyless); Anchor Lamp (Chimneyless); 'Tween Deck or Engine-room Lamp, for Mineral Oil, without a Chimney; 'Tween Deck or Engine-room Lamp, for Colza Oil, without a Chimney; Eclipsing Lights for River or Harbour use; Side Lamp Lens, in Three Pieces; Side Lamp Lens, as rolled from Mould; Side Lamp Lens, Cut and Finished.—*See Advertisement.*
William Harvie & Co., 222 Broomielaw, Glasgow.

618. **Diver's Air Pump.** An Improved Two-cylinder Double-action Diving Machine Air Pump, fitted with two Patent Indicating Gauges to denote the pressure and depth of each diver, wrought-iron crank, gun metal cylinders surrounded with copper cistern and water apparatus to keep them cool. Patent Cock arrangement for connecting or disconnecting the two cylinders.
Siebe, Gorman, & Co., London.

619. **Diving Helmet and Breastplate.** An Improved Diving Helmet and Breastplate, made of tinned copper, fitted with new constructed segmental screw to remove the head-piece

[illegible] of a [illegible], fitted with strong plate glass in [illegible] [illegible] collars and screws with which the [illegible] is [illegible] water-tight, also with outlet and inlet [illegible] valve.

[illegible], GORMAN, & Co., London.

[illegible] International Code Signals.
[illegible] Marine Department).

[illegible] International Code Signals.
[illegible] Marine Department).

622. **Boards** for distinguishing International Code Signals.
BOARD OF TRADE (Marine Department).

623. **Frames of Instructions** for saving lives in case of shipwreck in English, French, German, Italian, and Swedish.
BOARD OF TRADE (Marine Department).

624. **Framed List of Stations,** having Board of Trade Rocket Life-Saving Apparatus.
BOARD OF TRADE (Marine Department).

625. **Presentation Medals** given for the Saving of Life at Sea.
BOARD OF TRADE (Marine Department).

626. **Instruction Books** for Life-Saving Apparatus.
BOARD OF TRADE (Marine Department).

627. **Chart of Lighthouses** around British Coast.
BOARD OF TRADE (Marine Department).

628. **Framed Rule** of the Road at Sea.
BOARD OF TRADE (Marine Department).

629. **Photographs.** Life-Saving Apparatus Wagons.
BOARD OF TRADE (Marine Department).

630. **Framed List of Stores.** Life-Saving Apparatus.
BOARD OF TRADE (Marine Department).

631. **Working Model**—Life-Saving Apparatus.
BOARD OF TRADE (Marine Department).

632. **Series of Models** used in the examination of Masters and Mates for Certificates of Competency.
BOARD OF TRADE (Marine Department).

633. **Large Life-Buoy** (Act, 1874), solid Cork, will sustain 32 lbs. iron after 24 hours' immersion in water.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

634. **Large Life-Buoy,** uncovered, to show how they are made.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

635. **Ordinary Size Life-Buoy,** used for Deck purposes.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**636. Oval Life-Buoy,** used for hanging in Berths or Cabins.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**637. Yacht Life-Buoy,** also used for Berths and Cabins.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**638. Small Yacht Life-Buoy.**
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**639. Lifeboat Jacket** (Act, 1874), will sustain 23 lbs. iron after 24 hours' immersion in water.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**640. Life Belts for Passengers,** and also hung up in Berths and Cabins.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**641. Life Pillow,** made of Granulated Cork.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**642. Cork Mattresses,** made of Granulated Cork. These will sustain over eight persons.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**643. Sections and Cuts of Life-Buoys** to show solidity and how made.
STEEDMAN & M'ALISTER, Cathcart Street, off Paisley Road, Glasgow.

**644. Ship Binnacle,** with two revolving lamps for darkening compass card when necessary.
JAMES GILCHRIST, 14 Carlton Court, Glasgow.

**645. Ship's Binnacle,** with one lamp in tap and darkening disc. These lamps will not blow out with the wind.
JAMES GILCHRIST, 14 Carlton Court, Glasgow.

**647. New Tubular Buoy.** Ramsay's "New Tubular Buoy," for the combined service of Boat and Life-Buoy, sanctioned by the Board of Trade, and the Commissioners of Emigration. Sept., 1874.
ROBERT RAMSAY, Port-Glasgow.

**648. Tanks.** Ramsay's Tanks of Life-Boat Buoyancy, sanctioned by the Board of Trade, and the Commissioners of Emigration. 1879.
ROBERT RAMSAY, Port-Glasgow.

**649. Signal Light.** Holmes' Rescue Signal Light. These Lights have become compulsory for all passenger ships.
JOSEPH R. HOLMES, 175 St. Vincent Street, Glasgow.

**650. Fog Signals.** Holmes' Fog Signals. Two sizes.
JOSEPH R. HOLMES, 175 St. Vincent Street, Glasgow.

**651. Signal Flare.** Holmes' Patent Shipwreck Distress Signal Flare.
JOSEPH R. HOLMES, 175 St. Vincent Street, Glasgow.

**652. Holmes' Danger Flare Signal.**
J. R. HOLMES, 175 St. Vincent Street, Glasgow.

**653. Holmes' Patent Inextinguishable Self-Floating Projectile.** Used in cases of shipwreck, being fired from a mortar.
J. R. HOLMES & Co., 175 St. Vincent Street, Glasgow.

**654. Patent Socket Rocket Distress Signal.**
JOSEPH R. HOLMES & Co., 175 St. Vincent Street, Glasgow.

**655. Patent Life Raft and Folding Boat.** The Boat folds with four flaps, and weighs about 28 lbs., and is easily stowed.
J. R. HOLMES & Co., 175 St. Vincent Street.

**656. Water Heater.** By Hawksley, Wild, & Co., Sheffield.
J. R. HOLMES & Co., Glasgow.

# V. MISCELLANEOUS.

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**669. Stromeyer's Strain Indicator.** An instrument for measuring very slight variations in length, made visible by means of the so-called "Newton's Rings," as they appear when homogenous light falls on two slightly curved and transparent surfaces placed opposite each other. It is devised chiefly for investigating the strains which occur in iron ships at sea, and in exceptional positions on shore. It has already been applied to structures under hydraulic stress with very interesting results.

LLOYD'S REGISTER OF SHIPPING.

**670. Small Wire Rope-making Machine,** Working Model, with Rope in process of making.

WILLIAM BARTON & Co., 153 Scotland Street, Glasgow.

**671. Mahogany Case of Samples** of all kinds of Wire Rope.

WILLIAM BARTON & Co., 153 Scotland Street, Glasgow.

**672. Steel Wire Hawser.**

WILLIAM BARTON & Co., 153 Scotland Street, Glasgow.

**673. Bulwarks.** Models of Wire Work for Ships' Bulwarks, in various designs. Iron, Brass, and Copper Joint Cloth for Steam Joints and Boiler and Condenser Tube Brushes, full size.

WM. RIDDELL & Co., Makers, 142 Trongate, Glasgow.

**674. Case containing Samples of**—1. Best Best Galvanized Rigging Ropes. 2. Best Best Galvanized Formed Rigging Ropes. 3. Best Best Galvanized Running Gear. 4. Galvanized Steering Gear. 5. Galvanized Seizing Wire. 6. Patent Flexible Steel Hawsers. 7. Galvanized Communication Cord. 8. Galvanized Strand. 9. Galvanized Picture Cord. 10. Crucible Steel and Charcoal Ropes of all kinds, for Collieries, Mines, Inclines, &c. 11. Steel Ropes for transmitting power, and driving Machinery. 12. Copper Wire Ropes, made of round and square wire, for Lightning

Conductors, &c. 13. Brass Cord for ornamental work. 14. Ropes for sundry purposes.—*See Advertisement.*
RYLANDS BROTHERS (Limited), Warrington.

**675. Samples of Sailcloths, &c.** Samples of Storm Extra, Star Extra, Leith Merchant and Boiler Sailcloths, Warps for Trawlers, Lines and Foregoers for whale fishing, Ships' Rope from pure Manilla and Russian Hemps, and Fishing Lines, Twines and Cords for home, colonial, and foreign Fishings.
THE EDINBURGH ROPERIE AND SAILCLOTH COMPANY.

**676. Canvas for Ships' Sails.** Crown royal extra, first quality. Crown royal extra. H.B. extra.—*See Advertisement.*
RUTHERFURD BROS., Sailcloth Manufacturers, Glasgow.

**676a. Repairing Canvas.** Extra, all long flax, for repairing Ships' Sails.—*See Advertisement.*
RUTHERFURD BROS., Sailcloth Manufacturers, Glasgow.

**677. Yacht Duck,** 18 in., for the Sails of Small Yachts.
RUTHERFURD BROS., Sailcloth Manufacturers, Glasgow.

**678. Tarpauling Canvas.** No. 1 Tarpauling used for covering Hatchways, &c. It is made in 24, 30, and 36 in. widths.
RUTHERFURD BROS., Sailcloth Manufacturers, Glasgow.

**679. Sail Twines.** No. 1 Seaming Twine, and No. 1 Extra Seaming Twine.
RUTHERFURD BROS., Sailcloth Manufacturers, Glasgow.

**680. Packings, &c.** Cotton Condenser Packing Rings, with Brass Model showing application. Solid drawn Brass Condenser Tubes. Polished Engineers' Nuts and Washers. Long Glass Gauge Tubes, warranted to stand 1000 lbs. pressure to the square inch. Packings and Jointings for Marine Engines. Lappings for Engineer's Bolts. Canvas Fire Hose tested to 400 lbs. India Rubber Fire Hose (3 ply), tested and burst. Tube Fittings for Gas, Steam, and Water.
W. & A. WILSON, James Street, Bridgeton, Glasgow.

**681. Oldham's Patent Improved Piston Packing,** made on the principle generally known as "Mather & Platt's;" the substantial improvement being the substitution of a steel

coil spring cut from a solid weldless steel hoop instead of cast-iron coil springs or steel coil springs, made by coiling a steel bar on a mandril.

POLLOCK, MACNAB, & HIGHGATE, Firpark Iron Works, Shettleston, near Glasgow.

**682. Ventilator.** Sharp's Patent "Crown Ejector" Ventilator for Steamships, Sailing Vessels, &c.

JAMES MITCHELL, 48 Gordon Street, Glasgow.

**683. Metallic Steam Check, or Piston Rod Packing.**

JOHN DONALD & SON, 42 Cadogan Street, Glasgow.

**684. Anti-friction White Metal.** Ingot's Tangye's Anti-friction White Metal, for Screw Shaft or otherbearings.—*See Advertisement.*

TANGYE BROTHERS, Engineers, Argyle Street, Glasgow.

**685. Beldam's Patent Compound Metallic Elastic Engine Packing,** for High-pressure Piston-rods, Pumps, &c.

M. PARKER & Co., Agents.

**686. Silicate Cotton,** in various qualities and conditions, for covering steam pipes and boilers to prevent radiation.

A. B. KIRSOP & Co., 33 Hope Street, Glasgow.

**687. Steam-Engine Packing-joints, Millboards, &c.** Specimens of Asbestos Steam-Engine Packing-joints, Millboards, &c.

PATENT ASBESTOS MANUFACTURE COMPANY, LIMITED, 31 St. Vincent Place.

**688. Wood's Self-Adjusting Rivet-Hole and Leak Stopper** for Ships, Buoys, Boilers, &c.

J. W. WOOD, Harwich, Essex.

**689. Automatic Weighing Machine.** This Machine works with ordinary lever-armed Beam and Weights of Board of Trade standard denominations. The peculiar arrangement of its parts enables the weight scale to lift automatically the weights necessary to balance the package, and to exhibit in plain figures its exact weight. Model of 25 Cwt. Machine. Scale, 1½ in. to the foot.

JAMES CRAIG, Dellingburn Street, Greenock.

**691. Model of Patent Refrigerators,** for the preservation of passengers' and crews' provisions, especially in tropical waters, where ice is expensive.

THE BELL COLEMAN MECHANICAL REFRIGERATION COY., 45 West Nile Street, Glasgow.

**692. Boiler Incrustation Preventative** for preventing and removing Incrustation in Marine, Land, and Locomotive Steam Boilers.—*See Advertisement.*

BLACKLEY, YOUNG, & Co., 103 Holm Street, Wellington Street, Glasgow.

**693. Hannay's Patent Compositions,** for the Prevention of Corrosion and Fouling of Ships' Bottoms.—(*See Advertisement.*)

W. B. DICK & Co., Glasgow and London.

**694. Paint.** Half-Model and Iron Plate coated with M'Millan's Patent Antifouling Exfoliating Composition Paint.

ARCHD. M'MILLAN, 8 Kent Road, Glasgow.

**695. Half-Model of Steamer,** showing Rahtjen's Patent Antifouling Composition for Ships' Bottoms. —*See Advertisement.*

HARTMANN, NEWMAN, & Co., Glasgow.

**696. Half-Model of Sailing Vessel,** showing Suter, Hartmann, & Co.'s Patent "Empire" Enamel for Ships' Bottoms.—*See Advertisement.*

HARTMANN, NEWMAN, & Co., Glasgow.

**698. Collection of Drawing and Measuring Instruments and Materials** used by Marine Draughtsmen.

WM. FORD STANLEY, 485 Great Turnstile, Holborn, London.—*See Advertisement.*

**699. Case,** containing Timber preserved from decay; Timber rapidly seasoned; Timber increased in strength; Timber made to resist sea-worms, &c.; and Timber rendered non-inflammable.

A. GARDNER & SON, 36 Jamaica Street, Glasgow.

**700. Model of Patent Derrick Crane,** with Patent Safety Catch to prevent the jib from falling.
D. WATSON & Co., Hayfield Engine Works, Glasgow.

**701. Assortment of Short-Link Crane Chains,** showing their tensile strain. Also, Cable, Pit, Coil, Fencing, and Sugar Chains, made of special iron.
D. WATSON & Co., Hayfield Engine Works, Glasgow.

**702. Self-relieving Grapnel.** Jamieson & King's Patent Self-relieving Grapnel for catching Submarine Cables.
Sir JAMES ANDERSON, Eastern Telegraph Company, 66 Old Broad Street, London.

**703. Spare Spring-toe** (for Jamieson's & King's Grapnel).
Sir JAMES ANDERSON, 66 Old Broad Street, London.

**704. Grapnel.** Working Model of Jamieson & King's Grapnel.
Sir JAMES ANDERSON, 66 Old Broad Street, London.

**705. Grapnel.** Full-sized Drawing of Jamieson & King's Grapnel.
Sir JAMES ANDERSON, 66 Old Broad Street, London.

**706. Nipper-Lead.** Mr. Lucas' Deep-sea "Nipper-Lead."
Sir JAMES ANDERSON, 66 Old Broad Street, London.

**707. Cable.** Specimens of Cable picked up in lat. 43° 43′ N. long. 9° 16′ W., from 1120 fathoms, after six years immersion (14th June, 1876). Also three other Specimens from other depths.
Sir JAMES ANDERSON, 66 Old Broad Street, London.

**709. Cable Repairing.** Large Drawing of "Great Eastern" picking up Cable in water 2 miles deep (1866).
Sir JAMES ANDERSON, 66 Old Broad Street, London.

**710. Cables.** Drawing of Cables of various patterns.
Sir JAMES ANDERSON, 66 Old Broad Street, London.

**711. Portable Heat Generating Vessels,** for Warming.
WM. LESTER, 58 Renfield Street, Glasgow.

**712. Portable Heat Generating Vessels,** for heating Water and Cooking.
WM. LESTER, 58 Renfield Street, Glasgow.

**713. Gresham's Patent Woven Wire Mattress,** for Ships' Berths. Size, 5 ft. 11 in. long, by 2 ft. 4 in., by 6 in.
WM. LESTER, 58 Renfield Street, Glasgow.

**714. Revolving Gun Carriage** and Protective Cupolas for War Vessel.
THOMAS KINCAID, Greenock.

**715. Apparatus.** Instantaneous Port-closing Apparatus for War Vessel.
THOMAS KINCAID, Greenock.

**716. Specimens of Metals.** Small Case containing 176 Specimens of Metals and their Alloys.
D. C. GLEN, 21 Greenhead Street, Glasgow.

**717. Letter of Marque,** issued against Spanish Vessels in favour of Ship "Fairy," of Liverpool, 4th October, 1782.
JOHN KIRSOP, Queen's Crescent, Glasgow.

**718. Lubricator.** Self-acting "sight" Lubricator.
JOHN TURNBULL, Jun., 184 Buchanan Street, Glasgow.

**719. Packing Rings.** Set Patent Piston Packing Rings.
JOHN TURNBULL, Jun., 184 Buchanan Street.

**720. Patent Piston Spring Ring.**
JOHN TURNBULL, Jun., 184 Buchanan Street.

**721. Ships' Tonnage Scale,** for finding register tonnage, displacement, capacities, and proportions of ships and steamers from their dimensions, by use of comparative co-efficients or ratios of form.
GEORGE SCOTT, Shipbuilding Yard, Whiteinch.

"...." Built for the Barrow

forming one of the Anchor Line

dimensions—Length

... stroke ...

... at Barrow in 18.. by

Company. This is the ...

England, with the exception

... Street, Glasgow.

... and equipped, is ...

... Scotland. This

... ation of 1871, at

... of £...

... head, through Bally-

... and equipped, is-

... Artizans' See-

## ... ENGINEERING.

... "City of Liverpool."

... The Engines ...

... have Cylinders ...

... Each Engine has

... and an arrange-

... They are fitted

... Steam and Hydraulic

... improvements ...

... and safety ...

... made by Messrs.

... Propeller attached. The

... same as those employed

... the Propeller, which

... castings were supplied ...

... Foundry, and the brass

... James Cowan, of Hydepark

... Iron-works, Glasgow.

741. **Batchelor's Patent Working Diagram** of the Engines supplied by John & James Thomson to the Hall Line Steamers "Speke Hall" and "Wistow Hall."
John & James Thomson, Finnieston Works, Glasgow.

742. **Working Model of Engine,** with Crank Shaft passing through Piston. (Artizans' Section.)
Robert Shaw, 28 East Hamilton Street, Greenock.

743. **Model Pair of Marine Engines,** with Oscilating Cylinders.
James Reid, 31 George Street, Paisley.

744. **Working Model of a Horizontal Steam Engine,** with Patent Governor.
James Carlaw, Ropework Lane, Glasgow.

745. **Model of Jones's Patent Marine Boiler.**
C. Wilding King, 33 Bury New Road, Manchester.

746. **Model of Patent Helix Furnace Feeder and Smoke-consuming Fire Bars.**
Henry Field, Son, & Co., 196 St. Vincent Street, Glasgow.

747. **Model of Patent Rocking Furnace Bars.**
Henry Field, Son, & Co., 196 St. Vincent Street, Glasgow.

748. **Non-conducting Dry Hair Felt,** for Covering Boilers, Steam Pipes, &c.—*See Advertisement.*
Croggon & Co., 7 John Street, Glasgow.

749. **Ship's Sheathing Felt,** for Covering the Bottoms of Vessels.
Croggon & Co., 7 John Street, Glasgow.

## III. EQUIPMENT.

750. **Model of King & Cliff's Patent Steam Steering Gear.**
C. W. King, 33 Bury New Road, Manchester.

751. **Sectional Drawing of King & Cliff's Patent Steam Steering Gear.**
C. W. King, 33 Bury New Road, Manchester.

752. **Model of Patent Screw Steering Gear for Ships,** with Buffer or Strain-receiving Springs.
William Thomson, Portman Engine Works, Kinning Park, Glasgow.

**753. Model of Wilson's Patent Double-action Screw Propellers,** as applied to the propulsion of Whitehead Fish Torpedoes, &c.
ROBERT WILSON, F.R.S.E., Patricroft, Manchester.

**754. Collection of Steam Gauges, Engine Indicator, Engine Counters, and Engine-room Clock.**
DAVID CARLAW, 52 Ropework Lane, Glasgow.

**755. Case** containing Bourdon, Schaffer, and Silvester Gauges; square and round Valve Springs; flat, coil, and conical Springs; Piston Spring, Door and other Springs, Locomotive Balances, Lock-up Valve, and Signal Bell, &c.
GEORGE SALTER & Co., West Bromwich.

**756. Timmis's Patent Unequal Section Safety Valve Springs.**
Turton Brothers & Matthews, Sheffield, through ROBERT GORDON, 71 Finnieston Street, Glasgow.

**757. Ordinary Square Section Safety Valve Springs.**
Turton Brothers & Matthews, through ROBERT GORDON.

**758. Patent Machine-made Malleable Iron Side-light Gutters or Eyebrows,** for Steam or other Vessels.
THOMAS POTTER, 31 Canning Street, Glasgow.

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## V. MISCELLANEOUS.

**759. Ship Logs** for indicating the Speed of Vessels, and **Sounding Machines** to show the Depth of the Sea, **Log Line,** and **Bar Magnets, &c.**
THOMAS WALKER & SON, 58 Oxford Street, Birmingham.

**760. Model of Gun Dismantling Gear** proposed by Donald C. Grant (late of H.M. Dockyards), as originally fitted in H.M.S. "Northumberland," and for which the Admiralty awarded the inventor £100. The Gear, with improvements by inventor and modifications, is now in use in all H.M. Ships carrying heavy guns.
M. A. RENISON, 24 Oswald Street, Glasgow.

**761. Goudie's Patent Life-saving Waterproof Coat.**—*See Advertisement.*
JAMES T. GOUDIE & Co., 69 Jamaica Street, Glasgow.

# LIST OF EXHIBITORS.

The Admiralty Boilers' Committee.
Admiralty, Lords of the.
Aitken & Mansel, Whiteinch.
William Alexander & Co., Helen Street, Govan.
Sir James Anderson, Eastern Telegraph Company, London.
Arbuthnot Museum, Peterhead.
William Arrol & Co., Dalmarnock Iron-works, Glasgow.
Asbestos (Patent) Manufacturing Co. (Limited).
Austin & Dodson, Cambrian Works, Sheffield.

James Ballantyne, College Park Street, Dumbarton.
Barclay, Curle, & Co., Whiteinch, Glasgow.
Wm. Barton & Co., 153 Scotland Street, Glasgow.
Wm. Barwell, Hockley-works, Birmingham.
Bell-Colman Mechanical Refrigerating Co., 45 West Nile Street, Glasgow.
Birkenhead, Corporation of.
Blackley, Young, & Co., 103 Holm Street, Glasgow.
Blackwood & Gordon, Port-Glasgow.
Blake & Dane, Birmingham.
Board of Trade Marine Department.
Gilbert Bogle & Co., 47 Oswald Street, Glasgow.
R. Boyle, & Son, Glasgow.
John Bowers, City Chambers, Glasgow.
K. B. Brown, 28 High Street, Dumbarton.
Hugh Brown, 89 Elder Street, Govan.
Brown, Lenox, and Co., Millwall, London.

Caird & Co., Greenock.
Duncan Cameron, 52 Holmhead Street, Glasgow.
A. Campbell & Son, 29 Anderston Quay, Glasgow.
David Carlaw, Ropework Lane, Glasgow.
James Carlaw, Ropework Lane, Glasgow.
R. Chambers, Iron Shipbuilder, Dumbarton.
James Clark, Lugar Iron Works, Old Cumnock.
G. W. Clark, Dumbreck House.
The Clyde Trustees.
Clyde Yacht Club, Royal.
Daniel Cocking, 202 Hope Street, Glasgow.
Cochran & Co., Engineers, Birkenhead.
Charles Connell & Co., Scotstoun.
John Conner, 143 Norfolk Street, Glasgow.
Craig & Donald, Johnstone.
James Craig, Dellingburn Street, Greenock.
Croggon & Co., 7 John Street, Glasgow.
Cunliffe & Dunlop, Inch Works, Port-Glasgow.
Donald Currie & Co., Fenchurch Street, London.

James Dawson, 183 Wood Crescent, Dumbarton.
Dempster, Moore, & Co., 49 Robertson Street, Glasgow.
Alexander Denholm, Partick.
William Denny & Brothers, Dumbarton.
John L. Dexter, Bourne-end, Maidenhead.
W. B. Dick & Co., Glasgow and London.
Thomas Dobson, M.A., South Shields.
John Donald & Son, 42 Cadogan Street, Glasgow.

**722. Engineers' Boiler Scales.** A complete set of scales for the purpose of obtaining a ready result of the various formulæ for the construction of boilers and engines, as set forth in the Board of Trade Rook of Instructions to Surveyors.

GEORGE SCOTT, Shipbuilding Yard, Whiteinch.

**723. Sea Water with Iron Wire, which has been immersed in it for about Four Years.**

JAMES YOUNG, F.R.S., LL.D., of Kelly, Wemyss Bay.

**724. Sea Water with Iron Wire after four years' immersion.** In this case a little lime has been added to the water, and no corrosion of iron has taken place. See Mr. Young's paper on the Preservation of Iron Ships (*Proceedings*, Royal Society, Edinburgh, vol. vii., p. 702).

JAMES YOUNG, F.R.S., LL.D.